METRIC
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Sustainable Agriculture
deepening living soil to adsorb
Salt and CO2

Water for Every Farm

Yeomans Keyline Plan

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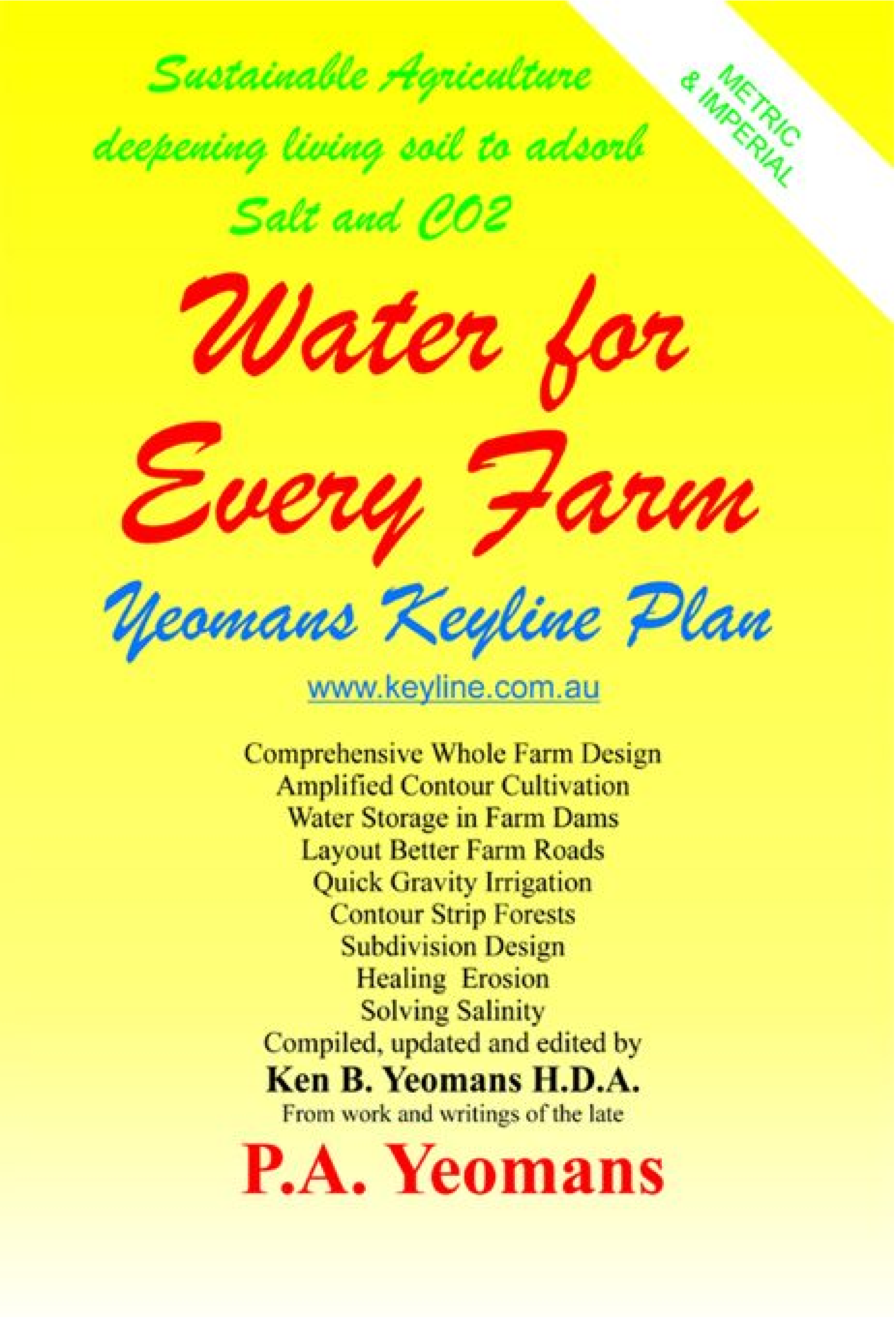
Comprehensive Whole Farm Design
Amplified Contour Cultivation
Water Storage in Farm Dams
Layout Better Farm Roads
Quick Gravity Irrigation
Contour Strip Forests
Subdivision Design
Healing Erosion
Solving Salinity

Compiled, updated and edited by
Ken B. Yeomans H.D.A.
From work and writings of the late
P.A. Yeomans



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Psalm 65:10
You water its ridges abundantly,
You settle its furrows;
You make it soft with showers,
You bless its growth. **(NKJ)**

Water for Every Farm - Yeomans Keyline Plan

Much of the material in this book was first published by the editors late father P.A. Yeomans in 1954 (The Keyline Plan), 1958 (The Challenge of Landscape), 1964 (Water for Every Farm), 1968 (Water for Every Farm 2nd Ed), 1971 (The City Forest). See the editor's preface for details.

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P.O. Box 3289
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AUSTRALIA.
Phone (07) 5591 6281 Mobile: 0418 745 120
International Tel: +61 7 5591 6281
Email: info@keyline.com.au
Internet: http://www.keyline.com.au

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CONTENTS IN DETAIL

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OTHER KEYLINE BOOKS (out of print)

The Keyline Plan

The Keyline Plan was published by Yeomans in 1954. This book became an agricultural best seller and sold out. It is still sought by collectors. Another edition was called for but it was obvious that as the concept had developed and a new book was needed.

The Challenge Of Landscape

The Challenge Of Landscape was published in 1958, in this Yeomans further developed his theories and practice of land development. The Keyline Scale of Permanence was first detailed in this book and provided a practical guide to property planning priorities. The use of Keyline pattern cultivation to enable the successful flood irrigation of undulating land from farm dams was shown.

Water For Every Farm

Water For Every Farm was first published by The K. G. Murray Publishing Company Pty Ltd, Sydney, N.S.W. in December 1965. The second edition was published in October 1968. In this book Yeomans, among other things, detailed the application of Keyline to flat land irrigation and further developed the techniques of irrigating undulating land. The flood irrigation of flat land at a rate of 8 hectares (20 acres) per hour with one-man control was shown to be eminently practical. This book explained many aspects of the plan: economic dam construction; locating farm dams; irrigation channel and steering bank construction; irrigated pasture management; fencing for maximum pasture utilisation; soil improvement and more.

The City Forest

The City Forest was published in 1971 as a paper back. This book extended the logical application of Keyline into urban design and proposed the use of effluent on Keyline planned and irrigated rain forests - city forests. It was used as a text book for many students studying Landscape Architecture in Sydney.

Water For Every Farm Using The Keyline Plan

Water For Every Farm Using The Keyline Plan was published by Murray books in 1978. This book was a compilation of the two earlier books named in the title. The compiled edition suffered some weaknesses: firstly it was only in metric, making it difficult to imagine for many readers and to make matters worse on occasions it was inaccurately converted to metric; secondly, in Part 1, the inaccurate idea that a Keyline forms a continuous line right across the landscape, called a “common” Keyline, was re-presented after non-use for thirty years. This point was somewhat clarified in Part 2 of the book, but these problems contributed to confusion for those going it alone with Keyline planning. This confusion was perhaps compounded by a few errors in metric conversion. In one case, referring to the once only application rate of pre-mixed superphosphate and lime fertiliser, the imperial measurement of 1 cwt per acre of fertiliser became, in metric, 1 kg per hectare, whereas it should have been about 125 kg per ha. Since 1981 Second Back Row Press Pty., Ltd., have twice republished this edition in paperback form. The cover is a beige colour.

The Australian Keyline Plan for the Enrichment of Human Settlements

Title of a paper presented by P. A. Yeomans to the Habitat Forum of the United Nations Conference on Human Settlements, Vancouver, Canada in 1976.

This Australian Keyline Plan submission to the United Nations Conference was with the sponsorship of the Murray Valley Development League.

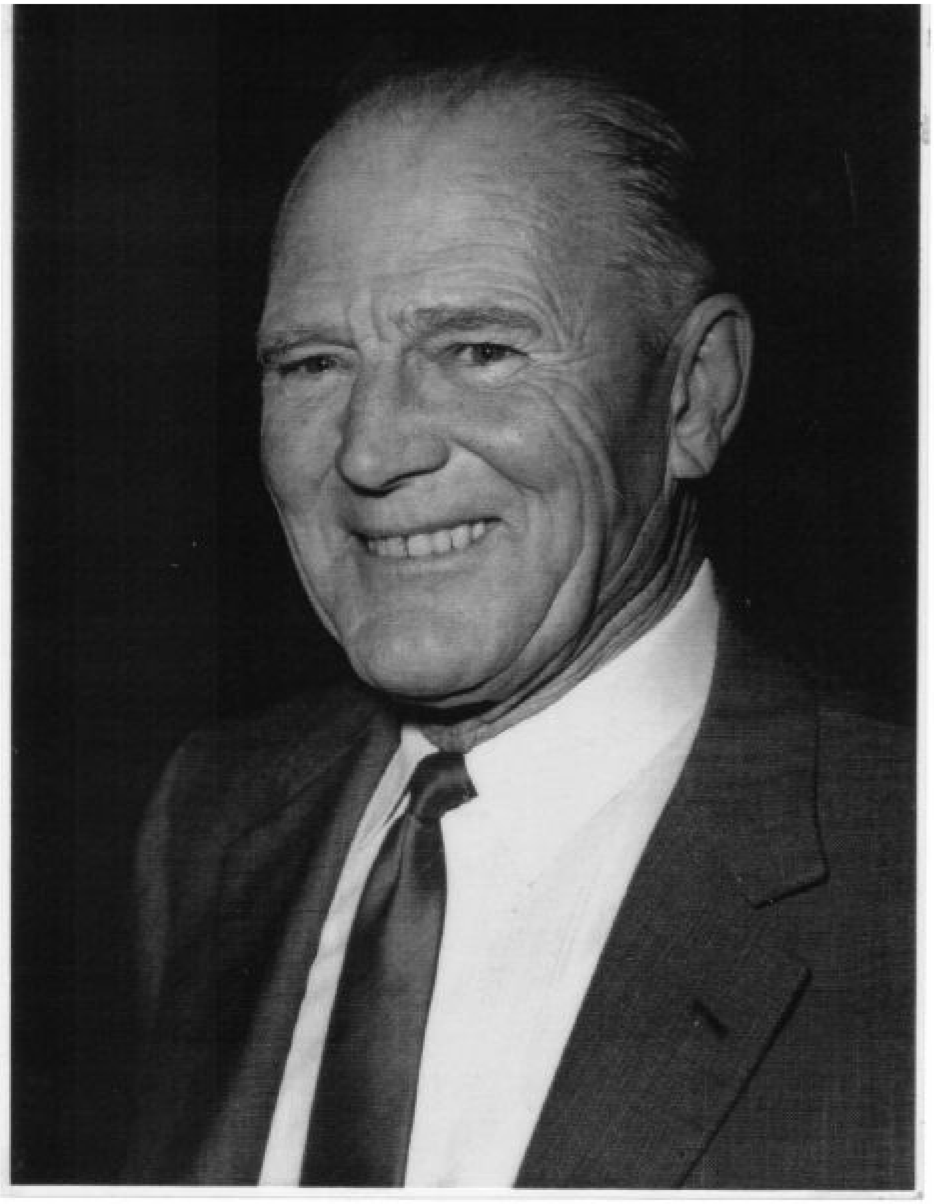


Plate 1 Percival Alfred ("PA") Yeomans 1905 - 1984

The Late P.A. YEOMANS - A Man Before His Time

by Allan J. Yeomans

Percival Alfred Yeomans (P.A.) was born in Harden N.S.W. in 1905, eldest son of a family of four. In 1928 he married Rita Irene May Barnes, also of Harden. They had three children; Neville born in 1928, Allan in 1931 and Ken in 1947. Rita Yeomans died 1964 and the two original Keyline properties at North Richmond N.S.W. were sold to pay death duties.

P. A. Yeomans married Jane Radek in 1966 and they had two daughters, Julie and Wendy.

Following this marriage he undertook the design and construction of a different concept in cultivation equipment. He solved the need for better equipment than the chisel plow to deeply loosen soil without bringing up the subsoil. This equipment was the first rigid tyned vibrating sub-soil cultivating ripper for use with farm tractors. It is many times more efficient than a chisel plow, and is able to loosen more soil to a greater depth using less tractor power.

The Prince Philip Design Award officially recognised the breakthrough success of this equipment in 1974 when P. A. Yeomans Pty Ltd received this coveted award for the Bunyip Slipper Imp with Shakaerator.

Manufacture of the Bunyip Slipper Imp eventually passed from P. A. Yeomans Pty Ltd to the Yeomans Plow Company, which is now based in South-east Queensland. This company is owned and directed by Allan J. Yeomans the second son of P. A. Yeomans. The equipment has undergone further developed including some landmark design breakthroughs and has been renamed the Yeomans Keyline Plow.

P. A. Yeomans devoted much of his latter life time to consulting, advising and lecturing on Keyline planning for which he has received requests from many parts of the world.

P. A. Yeomans passed away, aged 79 years, in November 1984.

Biography - P.A. 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.

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 arid 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 broad-acre farming. 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 is 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 sub tropical 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, has ever been accorded to his works. The changed and changing face of the Australian landscape however, is his immense and worthy memorial.

A. J. Yeomans
Gold Coast
Queensland
1993

1993 Edition: Editor's preface by Ken Yeomans

The production of this book was a much bigger task than I envisaged because it is more than just an edited compilation of the writings of the late P. A. Yeomans. It started out as an attempt to provide a contemporary edition of "Water For Every Farm", that at least had accurate **dimensions in imperial and metric**. It is also time to restate and clarify some of the original Keyline concepts, the **Keyline Scale of Permanence**, the ideas behind the placement of **Contour Strips Forests**, the **City Forest** and more. This valuable information was in danger of being lost from current literature as all former Keyline books are out of print. Often people have expressed their desire for a **more readable** book on Keyline development. Perhaps this edition will prove easier to read and understand.

P. A. Yeomans generally wrote as "I", the first person singular. In the editing of this book "I" has been changed to the plural "we", which he often used anyway. Exceptions are in anecdotal sections and where only his name can be used. The use of plural allows additional information to be woven into the material. It has proved impractical to make note of all instances where the original material has been modified. The chapter names and content have been edited in an effort to bring relevant sections together for ease of comprehension.

The bulk of the text of this book came from the second edition of "Water For Every Farm", which was written in imperial measurement. Relevant chapters were also included from "The Keyline Plan", "The Challenge of Landscape" and "The City Forest". Some of the line drawings in "Water for Every Farm using The Keyline Plan" originated in "The Keyline Plan", these have been omitted. All diagrams from the original "Water For Every Farm" have been included after re-drawing. **Extra diagrams** have been added wherever this seemed necessary. The monochrome photos used this book came from "Water for Every Farm using The Keyline Plan".

Water availability and soil fertility determine most of the productive potential of rural land, so it is definitely in the interest of the individual land holder to initiate the attack on water wastage and declining levels of biological fertility. This can best be done by using the techniques embodied in Keyline designs. In reality Keyline is superb "Landcare" to use a fashionable term.

The biological fertility of soil has been neglected and water wastage is a national problem. This is compounded by the totally mistaken belief that the soil can not be regenerated. Applied chemical fertilisers have been over emphasised. This distortion of priorities has resulted in the loss of the soil's biological fertility over vast areas. One result manifesting is an increasing cost of production, especially that of chemical inputs. Another result is the expanding area affected by soil erosion and salinity as the "living soil" dies. Now it is being acknowledged that wheat protein can not be maintained simply by adding more fertiliser. So in parts of Australia, at least, farmers have hit the wall at the end of the chemical farming road and they are looking for more ecologically and financially sound methods.

Landscape design often treats run-off water from heavy rain as a disposal problem. Unfortunately the *disposal* of rainfall run-off is an underlying requirement of Soil Conservation based property plans; urban subdivision and road work design. On the driest continent on earth what quality of future is possible when the underlying design of its farms and urban areas is the disposal of the rain water that falls on them? Keyline design solves this problem and much more.

Ken B. Yeomans Editor.

2001 Electronic Edition: Editor's preface by Ken Yeomans

This edition corrects typographical errors in the first edition. The data on the Burdekin falls irrigation project is updated and incorporated into the text and tables. The new information further confirms the original assessment.

Other photos have been incorporated into the text to further illustrate some of the concepts and practices.

2008 Edition: Editors comments by Ken Yeomans.

This edition has been produced to enable production in the USA.

The page size is changed. Wherever possible photos were rescanned. Some photos were added and all were adjusted to 300dpi greyscale. New photos and figures have changed the Plate and Figure numbers when compared to earlier editions.

Also you'll probably need to double the dollars amounts mentioned in this text. Our money continues to loose value and doubling the prices will somewhat compensate for the effect of inflation. Why double? Well if inflation has averaged, let's say 5% since initial publication of the book in

1993 and we apply the “Rule of Seventy”, which gives the doubling period for any constant rate of change 70 / 5 (% per year) = 14 years for prices to double.

I. KEYLINE - WHAT IT IS:

The Keyline Plan is a set of principles, techniques and systems, which coordinate into a development plan for rural and urban landscapes. The result is a strategic master plan to develop the natural or existing landscape through its regeneration and enhancement.

In a rural setting, Keyline is far more than a unique combination of water conservation and farming with nature. Keyline completely supersedes the widely imposed but misconceived North American concept of Soil Conservation.

Keyline is superb Land Care.

The Keyline Plan is to prepare the land to quickly absorb, and hold by way of improved physical and biological field capacity, an increasing proportion of its rainfall. Also the plan is to store surplus run off water, wherever practical, in large "on-farm" storages, for later use by gravity powered, rapid, flood irrigation. The design achieving this becomes a whole Keyline landscape regeneration and development plan. Components of the landscape design such as roads; contour strip forests; buildings and subdivision fit logically together within the plan.

One of the primary objectives of Keyline planning is to enhance the swift development of deep biologically fertile (living) soil in a systematically designed landscape. Developing and deepening the biological fertility will rebuild the soil structure and reduce wasteful run off. By using Keyline management techniques, the soil can be quickly developed to levels of biological fertility and structural stability that is much better than ever existed in the natural undisturbed state. Biologically fertile soil is naturally highly productive and does not respond to, therefore does not need, chemically processed fertiliser inputs to maintain production.

Keyline is the natural way to defeat the menace of soil erosion and salinity, simply as an incidental to total landscape betterment.

A principal aim of rural Keyline planning is to increase both the depth and the fertility of the soil, so that the soil of farming and grazing land is safe and permanent. Thus productiveness of the soil is increased and the quality of its products is improved. Soil is capable of dramatic improvement.

Keyline seeks to remould the landscape, firstly, by the proper assessment and appraisal of all the natural and renewing resources of each individual area on which it is applied and secondly, by special methods of planning. A plan based on water control and land management, which uses the resources to the utmost for the betterment of the soil and the landscape as a whole.

A. Producing deep biologically fertile soil

One of the primary objectives of Keyline planning is to enhance the swift development of deep biologically fertile (living) soil in a systematically designed landscape. Developing and deepening the biological fertility will rebuild the soil structure and reduce run off. By using Keyline management techniques the soil can be quickly developed to levels of biological fertility and structural stability that can easily be better than ever existed in the natural undisturbed state.

Keyline is the natural way to defeat the menace of soil erosion and salinity, simply as an incidental to total landscape betterment.

1. Producing Topsoil.

The cultivation, irrigation and stock management techniques, of Keyline are used to greatly speed up the natural process of living soil formation. Conversion of subsoil into top soil may, under natural conditions, occur at 10 to 15 tonnes per hectare each year. On Keyline farms this figure has been increased to 10 to 15 hundred tonnes per hectare per year during the conversion process, which usually takes two or three years. The numbers may be startling but this result is achieved by deepening the topsoil by 10 to 15 cm (i.e. 4 to 6 inches). Deepening the living top soil to 30 and 45 cm (twelve to 18 inches) is a practical short term goal.

Converting sub-soil into topsoil is achieved by improving the living conditions for aerobic soil organisms. These organisms need airspace and moisture, warmth and a plentiful supply of high protein food. Additional airspace and moisture are provided, in the soil, by using non-inversion, sub-soil loosening equipment, like the Yeomans Plow. The extra airspace will hold more moisture and the plant roots and organisms easily grow into this space. A high protein food source is the root of pasture legumes, but root systems are unavailable during plant growth, for rapid soil development some of the roots must be forced to die! This is achieved by eating down or mowing off most of the above ground parts of the plant. The best time to do this is prior to the plant flowering and setting seed. This timing is because at this stage of growth the root system is at its maximum size. In loose soil with warmth and moisture, re-growth will be fast and replacement roots are produced as the plant regrows. As this cycle of growth and decay is repeated it builds the soil’s biological fertility by accelerating the natural soil building process.

2. Cultivation to defeat erosion.

Keyline pattern cultivation looks like an amplified contour pattern in that the rip marks left by non-inversion sub-soiling or chisel type ploughs, loop higher through the valleys and lower across ridges. The corrugated furrows form a pattern which direct run off water toward the ridges from higher points in adjacent valleys. Keyline pattern cultivation reduces the concentration of water in the valleys and increases the moisture absorbed on the ridges. The usual procedure is to work parallel to and only on the upland side of any contour guide lines on ridges and parallel to and on the lower side of contour guide lines in valleys when below the Keyline.

Keyline pattern cultivation has made practical the low cost watering of undulating country and hillsides by the “Keyline pattern irrigation” system.

3. Hillside irrigation.

Keyline pattern irrigation became possible after the discovery and development of Keyline pattern cultivation. Keyline pattern irrigation enables the low cost watering of undulating country and hillsides. In the past, the only method of fully flood irrigating undulating country has been by the use of terraces such as are used to create rice paddies.

4. Flat land irrigation.

In flat country Keyline is often better. The storage ratios of farm dams improve. In suitable flat country, the unique “Keyline contour irrigation channel” has enabled: “Flood-flow Irrigation” the fastest, fully controlled, one man, gravity powered, irrigation in the world. Flow rates of around 10 ML (Megalitre s) of water per hour enable irrigation at the rate of 20 hectares, i.e. 50 acres, per hour when applying 50 mm of water. Inundation times are preferably kept to under half an hour. Traditional slow flood irrigation methods used in most large scale irrigation schemes drown aerobic soil organisms, cause crop deterioration and promote salinity.

The slow application of irrigation water is not part of large scale sustainable agriculture.

5. Beautiful benefits.

Keyline Design enables the economic development of living soil in a landscape by specifically designed the property to achieve these results.

Another benefit of Keyline planning is the increased profit that will come from reduced production costs and increased productivity resulting from greater soil fertility and improved farm water utilisation.

Well-designed landscapes can be beautiful and highly productive. There is great satisfaction to be derived from getting it right with regard to the development of the land. The hallmarks on the properties of successful Keyline farmers are lakes with water birds, contour and ridge line roads and tree strips, dark fertile soil, luxuriant healthy green crops and feed.

Visitors to Keyline farms are often amazed by how perfectly the property is suited to the scheme. Really it is a function of the Keyline planning.

The plan is unique to each property so the plan is always custom made to the property. Thus Keyline reveals the potential and develops the uniqueness of the property. Experienced planning is necessary to reveal the full potential of any property.

B. Factors that determine soil fertility

Soil, the raw material of all agricultural pursuits, owes its existence and its state of fertility and productiveness to many factors. The principal circumstances that have determined a particular natural soil are:

(1) the mineralogical and structural framework,
(2) the prevailing climate, and
(3) the soil's biotic associations.

These three factors in combination have also determined the type of the natural landscape, which contained or housed the original soil.

All present farming and grazing practises have involved a drastic interference with the previous landscape. Clearly it is this interference that is of concern to the environmental movement.

Although the natural order for any tract of land is one of continuous change, there was, in most natural landscapes that have later had any agricultural significance, a certain stability, which tended to preserve the general shape and form of the land against rapid change and remoulding of the surface. But with man's interference of the differing natural regions converting them into farming and grazing land, this stability has too often been lost. The result has been a rapid decline in the soil fertility, much of which was poor to begin with, followed by soil erosion and salinity in its various destructive and well-publicised forms.

However, by improved methods of planning and design based on the proper assessment of the resources of the land, man can now change the various natural landscapes in a beneficial way. At the same time and quite automatically he can exclude any possibility of further soil erosion and salinity.

The soil can be improved to a state of fertility well above that which has ever previously existed and the replacement panorama can be more stable and in better balance, than was the preceding one. The quantity and quality of production can be greatly superior to that of present methods of land conversion including, what has of late, been given the rather futile title of conservation farming.

1. Enhancing the factors.

Which of the three factors, which determine the soil type, can we readily control? (1) Not the mineralogical and structural framework as this is predetermined and not readily altered, (2) nor the climatic background which is likewise relatively fixed and not capable of control by the individual landowner, however (3) the biotic association is susceptible to control.

The climatic background may be considered as fixed. It may be arctic, temperate or tropical, maritime or continental. Also, it may be affected by large bodies of water and rivers, by hills, mountains and valleys and other local variations. However the particular effect that the prevailing general climate has on the microclimate within the soil is susceptible to great changes. Soil has an environment of its own which is absolutely crucial to the soil's teeming communities including bacteria, fungi, earthworms and the like. Changes to the microclimate within the soil are essential for the improvement of the soil. Thus man is given the chance to improve the soil microclimate and remake it.

Likewise, within the general climatic pattern, the concordantly planned and nurtured landscape of a farm may be given a climate of its own which is more favourable than that of the surrounding area. For instance, the climate adjacent to lakes can be decidedly better than the climate of the wider region, also a farm which has had its water resources developed for storage in farm dams. The irrigation of dry areas with water brought from a distant supply is also a notable example of the modification of soil and landscape by man.

2. Keyline planning based on permanence.

'Keyline' plans the development of the replacement landscape on the two most permanent features of the natural landscape:

(1) The climate, which in large measure has moulded and determined its present topography and,

(2) The existing shape and form of the land with the underlying influence of the geological structure of the area.

Of the various elements of climate, heat and cold, wind, water from local rainfall as well as from lakes and streams, the factor of water is the one most susceptible to control. Therefore in order to assess the water resources of any area, farm waters are divided into four categories so that, for Keyline purposes, these water resources may be better understood and evaluated.

a) Water control paramount.

In circumstances where water from rainfall is generally in short supply while at other times there is run-off from rainfall, the plan for the control of water involves earth works such as channels and drains, and walls for storage dams. These new water lines become permanent features of the new landscape and have precedence in design over other and less critical components of the planned landscape.

Because of the physical properties and behaviour of water, these and all other water lines are critical and invariably become the framework to the Keyline plan for the land. This principle still applies even when water is in excess. All other constructional aspects of planning, such as roads, tree planting, locations for farm buildings and working paddocks, subdivisions for crops, pastures and livestock, are fitted into the basic “water lines” framework.

But since the course of water is determined by the landform over which it flows, all water lines over the land are unique to each estate because of the variations in topography. The various component shapes of land have been classified in order to fully understand and assess and plan water control and water movements. A section of this book deals with the geography of Keyline.

Again, within each of these geographical classes there is a typical pattern in the contours of these shapes of the land. The section on the geometry of Keyline permits the use of these patterns by disclosing techniques based on them for the better use of direct rainfall and for the even spreading of irrigation water through the soil. Each of these functions also form part of the soil improvement techniques of Keyline.

While water is the principal aspect of climate where improvements of the soil’s climate and the confined landscape’s climate may be effected, there are other features of the general climatic pattern, which may be modified, in the reformed or revised landscape. Notable also is the damaging and moisture-robbing power of drying winds, which may be appreciably reduced by the planting of tree belts in strategic locations.

b) Enhancing the soils biotic associations.

The third factor determining soil fertility, the biotic associations within the soil, is almost completely under the dominion of man in the unfolding landscape.

While it is true that the first result from Keyline techniques for enriching the soil will be seen in the more luxuriant growth of plant life, plants themselves have the faculty of improving the soil and further modifying the soil-climate for continued soil improvement. It is fortunate indeed that so many of these plants are of a very high nutritive value in themselves. They include in their benevolent and beneficent array many species that are suitable for pastures, especially the legumes and other deep rooting grasses and herbs. Likewise many vegetables, which by themselves or in close association with other specific plants, have amazing soil building properties. There is also a wide variety of tree and shrub species that are beneficial as well.

In widely differing climatic circumstances, the planting and proper management of particular plant species are eminently practical in producing dramatic improvement in the fertility and productiveness of even the most unpromising earths.

Sub-soils, remaining on farm and grazing land after the real soil has been lost by erosion, have easily been transformed into fertile and highly productive soil in two or three years. This conversion can be accomplished economically by precise management of existing or sown pasture species and Keyline cultivation. However conversion is only part of the story.

If soil is the basic raw material of agriculture then the permanent home for any really worthwhile soil must be a properly planned and developed landscape.

Throughout time, the soil, like the crops and livestock it produces, persists and develops as thinking man assists nature by using and accelerating her own timeless processes. Man can enrich his own life and that of later generations as after all, agriculture should be the human betterment of a continuous natural process.

Of all the men who work on the land, the grazier has the widest opportunities for improving the soil and imprinting his own image on the whole landscape. Pasture is the great healer of land (lay pasture) and stock provide the biological accelerators for the soil forming process. The grazier lives closest to these associations and usually commands an area of sufficient size that he can develop more of the landscape's potential.

Again it must be recognised that farmers and graziers can actually make their own fertile soil, thus making good land better and progressively yet rapidly converting poor soil and land to high fertility and more economic production. They will do this as an incidental to the process of production by following the best methods of land and water planning and management. Land subdivision by good fences also plays a vital role.

On any landscape, the particular climate, both past and present is one of the greatest of all influences on the quality and productiveness of the soil. For instance, if two differently located soils were alike in every other possible respect save only that the rainfall differed, then the soil receiving say 600 mm (24 inches) of annual rainfall could be worth from five to twenty-five times the value of the other, if it had a rainfall of only 250 mm (10 inches).

The influence of no other aspect of the climate on soil can be altered and so beneficially changed as can that of water, and likewise no other factor of agricultural influence can be so beneficially altered by proper planning as can water.

Water and rainfall are thus the bases of land development planning and no land subdivision has even a chance of being correct unless it has been planned to fit in with and facilitate the planned control and development of all the available water resources.

Furthermore the planning of the development of land should be based on permanent factors, namely, the twin agricultural permanencies of land shape and climate. As the one factor of climate that permits planning and control is water, so again land planning resolves itself first and foremost into an understanding of the two factors of land shape and the related water movements.

(1) Natural water lines

There are various types of natural water lines of land such as stream courses and water divides. Water flowing over land has a pattern of flow and predictable path lines of movement. The contour concept is a water line principle and nature's water line of a lake surface is a true contour line marked out on the land.

(2) Artificial water lines

There are other more artificial water lines and the farmer, when he understands and accepts the principles of planning and design indicated by these natural water lines, soon realises this fact. For example artificial water lines can reveal from where a stream can be diverted and to where it can be taken. Artificial water lines cross the natural water divides to divert water to fill dams, ponds and lakes of our own making. A pattern of cultivation can be produced that will intercept water flowing over the land and spread the water. An exaggerated contour pattern of cultivation will keep the water longer on the ridge shapes where more may be absorbed. This in turn reduces the losses of rainfall run off by simply keeping the water from concentrating in the valleys.

In 'Keyline' all farm dams are equipped with a lock-pipe system. This is a large (300 to 600 mm diameter) pipeline beneath the wall of the storage dam that releases water, by gravity from the dam into a channel for irrigation. The Lockpipe system and its associated irrigation channel forms one of the most important artificial water lines on the landscape. Below the irrigation channel the soil's climate can be dramatically improved through the supply of water by gravity. Above the channel is only 'rain' pasture. In flat country the irrigation channel water line may be permanently etched on the land surface as a wide irrigation channel. The flat land irrigation channel is built up so that water flows on the surface of the land and this water line is near to or actually on the true contour. The path lines of water movement below this channel may be reinforced with earth banks that follow the course of these lines to maintain the forward and down-land movement of irrigation water over the flat irrigation land. The irrigation channel water line in flat country differs from that of undulating country. The irrigation channel in undulating land is excavated like a long trench. The water flows just below the level of the lip on the lower side of the channel. This type of channel has a more positive fall, which may be as great as 0.33% (1 in 300).

There is another series of water lines which will operate in excessive rainfall climates, where the principal reasons for the interference with the natural water lines is for the express purpose of improving soil by enhancing the natural drainage.

Usually, to improve the use of available water resources, the artificial water lines are positioned to transport the water in the same direction, but on lesser fall, as the natural drainage lines of the stream courses. However in conditions of a general excess of water these man-made artificial lines for drainage may carry the water flow temporarily in the opposite direction.

If the aim of land planning, development and management is to make the best possible use of all the natural and renewable resources available then all these natural and artificial water lines of land are specially important.

These natural and artificial water lines are usually not straight lines and yet subdivision fences must be fitted into the water line scheme of things in order to even approach the goal of completely efficient water resources development, along with its effective use and management.

Though fairly wide publicity and acceptance has been given to the above ideals, the customary methods of orthodox land development are still continued despite their low efficiency. Consequently it is uncommon to see an irrigation farm dam that has been correctly located in relation to the adjacent water resources. It is even more uncommon to see the water used by the most rational methods of control and irrigation.

There is a another major advantage on a property which has been properly planned on the basis of its own climate and land shape; with its associated water lines of all kinds being fully disclosed, whether it has irrigated land or not. This advantage is that trees can be planted in the correct locations for the present five, twenty and many more years hence, as the farm or grazing property continues as such. Indeed it will be found in some situations that the planting of adequate trees may eventually be the sole reason for the property’s continuance.

The basic idea underlying Keyline development is continuity, even though this philosophy has not been the characteristic feature of African, Canadian, American or Australian philosophy, much to their detriment. Attitudes have changed and now there is a need for a permanent agricultural tradition, one that is sustainable. For this tradition to be successful it must be based on an appreciation of the design that already exists in the natural landscape.

II. THE LANDSCAPE DESIGN IN NATURE.

A. The Geography of Landscape.

There is landscape design in nature. It is made up of three water lines and three land shapes. It includes also three landforms and one special pattern.

We explore the origins of landscape in order to learn how to design better landscapes for ourselves.

In the beginning the world was formless and empty. On the third day of creation God said, (Gen 1:9 -10) "… "Let the water under the sky be gathered to one place, and let dry ground appear." And it was so. God called the dry ground "land," and the gathered waters he called "seas." And God saw that it was good."

The boundary between the land and the seas was a contour.

THE FIRST LANDSCAPE DESIGN LINE IN NATURE IS THE CONTOUR WATER LINE. A natural contour line shows where the surface of water at rest makes contact with the land.

THE SECOND LANDSCAPE DESIGN LINE IN NATURE IS THE WATER-DIVIDE LINE. The draining of the water back to the sea divided the land surfaces into watershed regions. It separated all the lands of the Earth into great regions and divided all the land within them into lesser regions.

THE THIRD LANDSCAPE DESIGN LINE IN NATURE IS THE WATER-DRAINAGE LINE. The water drainage line is the centre of the watercourses, the streams and the rivers and in the drainage lines of the land; we see a universal branching and joining pattern.

After the great flood the attack by water against the land and the draining of the water back to the sea abated. Though other forces of land disintegration, namely wind and fire combined with water to fashion and sculpture the earth's surface while much of the land was lost to the sea. The result was the foundation to the GREAT REGIONAL DESIGN IN NATURE, and the shapes and the forms of the land.

Life was deployed to protect the land from the assault of water, wind and fire. Life provided a resilient element of stability to the landscape. The movements of the water over the land were slowed down by the vegetation and the life in the soil. The vegetation protected the earth from the wind and the burning heat of the sun. Natural landscapes developed as life became more numerous and varied.

In the stabilised landscape there are three shapes of land defined in Keyline; the main ridge, the primary valley and the primary ridge.

The main ridge is the first land shape. It carries the water-divide line and is thus the boundary of all the regions of natural landscape design. Look at the skyline of a natural landscape; it reveals the line of a main ridge.

A main ridge almost surrounds the catchment areas of the great river systems of the world; a main ridge almost surrounds the catchments of every watercourse and stream within these regions. The ’almost’ indicates there is a low place where water escapes from the confining region and main ridge, as it does where two streams join and where a river flows into the sea. Naturally there is an exception to this, which is when the drainage basin is that of a lake or an inland sea, and then the main ridges do join up to form a continuous line.

Just as all the low places within the great regions are connected up by the joining of every water course, stream and tributary river to the main river, so also are all the higher places - the ridges, with their water-divide lines - connected up from the smallest ridge to the largest main ridge. This fact was vividly demonstrated with a hollow and thin fibreglass model of and actual landscape. When turned upside down and sprayed with water, it disclosed what could have been the working model of a different landscape. The valleys and ridges were reversed; the stream courses became the main ridges, the main ridges became stream courses. The hills became lakes - a lake is an upside down hill. The branching and joining pattern of the ridges was clearly disclosed.

Part of the landscape design in nature is the intertwining of the branching and joining pattern of the two water lines - the drainage lines and the water-divide lines. Together they form an almost never-ending interlacing, yet the two different water lines do not touch each other. They disclose the anatomy of the landscape.

The water drainage lines are obvious in the watercourses, the creeks, the streams and the rivers. The water-divide lines of the ridges are not so readily seen.

To illustrate the water-divide line and to examine the shapes of the land, imagine we stand between two creeks where they join on the cleared and undulating land of a farm. We turn our backs on the junction and walk uphill away from it following the highest land between the creeks; the land widens out as we go. We are walking along the crest of a main ridge -on a water-divide line - but we cannot see it. If it were raining heavily we could see it. The rainwater would be flowing away from the water-divide line in both directions, some to flow to the creek on our left, the rest to the creek on our right. Eventually the water would join up and flow together at the junction we left behind us.

The crest line of a ridge and the water-divide line are synonymous. The crest of a road and the ridgeline of a roof are water-divide lines; water flows in opposite directions from both.

From the main ridge the two creeks are in view and the sides of the main ridge slope, more or less uniformly, to the creeks below. Valleys form into the side of the main ridge. They are named primary valleys. The side slopes of the main ridge left standing, as it were, on each side of these valleys are also called ’primary’ - primary ridges.

There will be few or many primary valleys and primary ridges belonging to each main ridge. Since the primary valley has a primary ridge on both sides of it, there is always one more primary ridge than there are primary valleys in any main ridge system.

The primary valley is the smallest of the three shapes of land. It is the first valley and the only true valley shape in the landscape. The so-called valleys of streams and rivers are in reality; watershed areas - Nature’s regions - and they contain both primary ridges and primary valleys.

The primary valley has a special shape. The steepest slopes in the landscape usually occur in the centre of the valley above the Keypoint. This first steep slope at the head of the valley is short, then the slope changes to a more gradual and longer slope that extends to the creek (or valley junction) below.

P. A. Yeomans identified this area as the Keypoint of a primary valley. The concave, curving, contour line through the valley’s Keypoint is the Keyline of the valley.

ONLY A PRIMARY VALLEY HAS A KEYLINE.

The primary valley collects most of its water from the surrounding ridges; from the main ridge into which it intruded and from the primary ridges on either side of it. Runoff water flows into and down the primary valley during sufficient rain. The streams in the primary valleys are the first to cease flowing after the rain.

In the wide agricultural areas the primary valley was grassed over and of a smooth rounded bed, down which the run off waters from rainfall flowed - that was before so many became eroded into gutters and gullies, to bleed the moisture from the surrounding land.

The primary ridge is the largest of the individual shapes of the land. Because there are many more primary ridges than main ridges and because the primary valleys are the smallest, shape, the primary ridges include more of the land surface than the other two shapes combined.

From the crest line of the main ridge it will be plain so see that the main ridge is not level or even uniformly rising. It may depart from its general rise and dip down, then rise again. The low place is a saddle in the main ridge and it often shows where a primary valley has intruded deeply and reached the crest line of a main ridge. When the saddle is deep the first steep slope of the primary valley may be gone. The Keypoint of such a primary valley is the saddle.

A saddle is a unique landform that has significance for land planning. Road makers make use of the saddle of a main ridge to cross over from one watershed region to the next.

The descent of the centre line of a main ridge into a saddle has left a higher piece of land sticking up on the main ridge. This landform is a hill. It often has a saddle on each side of it.

The third landform is displayed in the depressions of lakes and ponds.

Continuing along the crest of the main ridge, a place is eventually reached where it appears to go two ways, as indeed it does. To the left the main ridge continues to almost surround the creek on our left and the right branch goes on to almost surround the creek on our right. But the main ridge of the water shed regions of the two creeks have now joined up with other main ridges, which surround other creeks and streams and provide the boundaries for their separate watershed regions. They have become a part of the main ridge system of the design in Nature.

Each of the two creeks has its own region bounded by the crest line of its own main ridge. These regions thus include all the land from which rainfall run-off water flows to each creek. The land covers one side of the surrounding main ridge that slopes towards the creek and consist of the series of primary valleys and primary ridges, which likewise fall from the side of the main ridge to the creek below. This is the basic, the single, THE UNIT REGION OF THE LAND. It may occupy only one or many square kilometres (half a square mile or many square miles).

The main ridge which started between the creeks at the junction, divides and the two branches becomes widely separated before they come closer together at the single stream below the junction of the two creeks. This main ridge without the branch between the creeks is thus the boundary of a larger region - a twin region - that includes the two single unit-regions of the two creeks. In like manner all the regions in Nature expand in numbers of unit-regions within them, where each larger region has its own main ridge, up to the largest region in Nature. It may contain half a million square kilometres (or miles) and embrace the entire watershed region of a great river.

This is the landscape design in Nature. It is repeated endlessly to cover the land surface of the Earth. But what is the purpose of this design?

The purpose of this design can be seen in its function. It protects the land from the attack of the waters. The waterline design and the land shapes appear to be designed for no other purpose than to get rid of water as quickly as possible. The shapes of the land reach the absolute in efficiency for achieving this objective.

The harmony of pure design in the landscapes in nature is the result of land's long battle against waters constant call - "come back to the sea".

The many and varied geological structures below the surface of the land, have provided the natural landscapes with character and variety. This variety is substantially composed of the three shapes of land - the main ridge, the primary valley and the primary ridge -something more to add to the wonder of the landscape design in Nature; for each of the three shapes of land there is a unique and constant geometry which is disclosed in their contours and which will shortly be reviewed. In combination with their depths, lengths and widths, there is endless variety. But multiplied by the effects of the profusion of climates, variety approaches infinity. Yet our manmade landscapes so often reflect only monotony and boredom.

B. The Geometry of Shapes and Forms.

1. Contour Lines

The contour lines in seas and lakes have been borrowed and are used as a device by the many professions concerned with land-use, so as to illustrate in a practical and accurate manner on paper, the shapes and forms of the land surface.

A contour line surrounds the land. A contour line surrounds the water - of lakes and ponds. The waterlines around a swimming pool or a bath are contour lines.

For the purpose of illustrating on paper the lines used on ’contour’ maps where the individual contour lines show where the land is the same height as indicated by the contours. The lines are placed to show set vertical distances below each other, such as one, five, ten and twenty metres (or feet).

On a map the highest contour line is placed as if all the contour lines that indicate lower land, were under the water of an imaginary lake and this first contour line was part of the shoreline of the lake of an island in the lake. The next contour line of the map, say 3 metres (10 feet) vertically lower than the top line, is again part of the shoreline when the water of the lake has dropped 3 metres (10 feet) -and so on downwards.

The contour lines on a map show the shapes and the forms of the land and the positions and relationships of watercourses and ponds. They show also how water will behave anywhere on the land, because the natural path of water flowing over the surface of the land is always at right angles to the contours of the land. This natural path of water is the steepest and fasters rout, but it is never a straight line; it always forms a flat S curve from ridge to valley.

2. The main ridge

The main ridge is the top of the land, the backbone and the outline of the landscape.

The contour diagram of a main ridge displays the contours as a series of elongated curves. Each one is outside the sweep of the curve of other as they progress downwards. The distance between the curves is wider down the crest line of the main ridge and narrower elsewhere.

3. The primary valley

A primary valley is the result of an intrusion of a simple valley shape into the side of a main ridge. The catchment area of a primary valley is the water divide along the main ridge above it and the water divide down the middle of the primary ridges on either side of it. The upper slope descending to the start of the primary valley is steeper than the adjacent slopes.

4. The primary ridge

Away from the centre of a main ridge the elongated curving pattern of main ridge contours change to a series of flatter curves revealing the pattern of primary ridges on the side of the main ridge. Between these flatter curves are the closer together contours indicating the boundary to the primary valleys. The curve patterns of the primary ridge contours appear to be more the shape of circle arcs than the hairpin like curves of the main ridge. The contours are widest apart at the centre of divide line of the primary ridge and narrowest at the head of the primary valley.

The primary valley has two slopes; the upper slope is steep and changes to a much flatter slope at the Keyline of the valley. Below the Keyline the sides of the primary valleys are steeper than the slope of the valley's centre line.

A line through the contours, joining the points of greatest convergence on each side of the primary valley, marks the boundary between valley and ridge shape. This can be seen marked in figures 11 and 12.

The combined contour pattern of the three shapes of the land may change again near the creek below, by the contours coming closer together near the centre of the primary ridge and being wider apart in the primary valley. This new pattern indicates that the primary ridge had 'nosed over' just above its lower boundary, which is the start of the valley pattern of the creek below.

Underlying geological formations modify this basic pattern in innumerable ways.

5. Saddles

The landforms of hill, saddle and pond also have their contour patterns. If there is a saddle in the ridge at the level, say, of the second contour, the two top contours will be elongated ovals to display the hill on the main ridge. Near the saddle they may be closer together or sometimes further apart. A saddle point is always on the crest line (water-divide line) of a ridge. A saddle point can be, on occasions, the Keypoint of a primary valley or more often is at the top of the first steep slope of a primary valley. A hill on a primary ridge will have the same closed contours, each outside the other, but with the oval form less pronounced or gone altogether.

From a saddle point, contours go four ways. If there is another saddle at the same height or lower, the contours join up and form a figure 8 shape.

The contour diagram of a pond displays the same pattern as a hill, but the inside contour is the lower line and the outside contour, the highest.

Since the main ridge rises into the rising country towards the head of the watershed, the height of the Keylines of the series of primary valleys tend to have a rising relationship also.

The creek is the lower boundary of its tributary primary valleys. The primary ridges end where they reach the valley pattern below them.

Run off water from rainfall on the man ridge and the higher parts of the primary ridges, flows to the primary valley by the steepest path and the fastest route.

The stability and permanence of the natural landscapes depend largely on the fertility and the strength of the primary valleys to resist the force of flowing water.

If you look for a primary valley in a city you may not recognise it so easily. It has been disguised by being overlooked and by our education, which ignores it. Even if you look at a primary valley in the cleared countryside you will not see the Keyline, unless a farmer has marked it with a water channel or has disclosed it with the water line of a farm dam. But you may discern the Keypoint where the two slopes of a primary valley meet.

If you go out in the country and find the Keypoint of a primary valley and stand there with your back to the valley below, you will see the AMPHITHEATRE OF THE LANDSCAPE. If this place were filled with people you would be the centre of the stage. In the same way if a sheet of water flowed from all around the highest tier of the theatre, you would cop the lot.

The function of the primary valley in the landscape has been overlooked by those who were responsible for devising the special purpose landscapes of man - with one exception. By accident or by instincts developed from long and intimate association with the land, a few farming families have improved and strengthened the primary valleys. In doing so they increased the fertility and the durability of their landscapes.

There are thus special shapes and forms disclosed in the landscape design in nature for consideration when we attempt to superimpose on them the special purpose landscapes for ourselves. Consider the efficiency of the shapes of land for getting rid of water. Rainfall run-off from the ridges, which occupy so much of the land concentrates in the primary valleys that are so little of the land surface. Water flows from farming land in the same efficient manner as it does from the natural landscapes. Therefore much water passes without being used effectively in the landscape. By slowing water down and storing it the water is retained for the benefit of the landscape. The cheapest place to store water is in the soil, for use by pastures, crops and trees, then store surplus in on-farm storage dams.

6. Natural balance

Natural waste products from plants and animals and from artificial substances used on the farm are all too often rushed to the watercourses to pollute the common waters of the land and the seas. This type of pollution, when it does not contain artificial substances, is named Primitive Pollution.

The natural landscapes had come to terms with the water. A stage of balance existed which was in accord with the amount of water available to the land. Where the rainfall was high and reliable, rain forests had developed; where the rainfall was moderate and its incidence less reliable, the grasslands of nature were found. When the man made landscapes of farm and city were imposed on those of nature, the balance of the association of land and water was changed. The flow of water off the landscape was sped up, instead of being slowed down.

It is evident that landscape design must firstly be concerned with water. It must plan to positively control and use more effectively the water, which falls on the ridge shapes. It is how this water moves to the watercourses that determine much of the flow characteristics of those watercourses.

The design that achieves the optimum control and beneficial use of water in the landscape will be the logical design for farm, townscape, and cityscape and for all the special purpose landscapes of man. Good landscape design will enhance the balance and stability of the landscape and this is necessary for any realistic attempt at the elimination of pollution.

Life in the landscape of nature is principally a process of slowly moving water: even our own bodies are 70% water. Life slowed down the water. Surely the next step is to control and to use water for the aggrandisement of all the special purpose landscapes of man before it reaches the streams and the rivers.

The landscape design in nature has been examined on undulating land, but the design and the shapes and the forms of the land are still there in the ’flat’ country. The shapes and forms may not always be identified by the naked eye. They will however be revealed by displaying the contours of the land on a map or on the ground with the aid of a levelling instrument and many pegs.

7. The primordial landscape

There is the primordial landscape with its vistas of mountains crags and caps and panoramas of cliffs and chasms where the hard geological structures below appear to have thrust through the landscape. There may be only a thin soil, here and there, which supports a few patches of scrub or scattered trees among the rocks. Even in this harsh angular land there will be the water-divide lines of the main ridges and the drainage lines of the water courses all twisted and bizarre. With the rocky foundations of the primary valleys and primary ridges, there will be the rough landforms of saddle, hill and pond.

The wind has intervened in the battle of water and the land. The signs of its victories are the hill forms in valleys, which have created many saddle forms, and pond forms that may not hold water. Where the structures below are pervious and on the strips of dune lands, the drainage lines of nature have been obliterated. But where water has made good its retreat back to the seas to attack again in rain and has re-established the drainage lines, the wind and the water have fashioned landscapes of sparkling variety. There are occasional flood plains where deeply flowing water has fashioned landscapes like those of the dune lands of many hill, saddle and pond forms.

8. The Fragment Between

There are fragments in the landscape. They have great importance but are not always of the three shapes of the land. These fragments are land which is covered with water some of the time.

a. Tidal areas

The tidal areas are land at low tide and water at high tide. In various places such as Holland tidal areas have been reclaimed for agricultural production.

b. Flood plains

The flood plains of streams and rivers are land for most of the time and become water once each year over many parts of the world. In Australia it is different, the weather patterns do not produce the regular annual flooding. On the other hand the flood plain of the Hawkesbury River, near Sydney in New South Wales, was covered by water six times in five weeks in 1951.

This land-water or water-land should be kept inviolate from wrongful intrusions. Towns and buildings or stock care centres should not intrude.

Towns were moved off this particular flood plain by Governor Macquarie in 1810. They are known as the Macquarie towns - Richmond, Winsor, Wilberforce, Pitt-town and Castlereagh.

These fragments are the thickening of the vital contact lines of water and the land. They are, as it were, adored and courted by each or the antagonists in the battle of water and land. It is always the front line, the fragment between, the piece in the middle - but it must not be a no-man’s land. It should be cherished and kept for the landscape.

Through all history man has battled man and illogically fought with Nature over these vital water lines. Now mankind at last should appreciate that the contact line of water and land has become his battle line for survival.

Yet in all the special purpose landscapes of man, the movement of the water off the land has been speeded up instead of being controlled and slowed down. Water moves faster off the farms than it did from the former natural landscapes, while the farms carry more animals that provide waste products that are washed to the streams and pollute them. Rainfall run off water rushes from the roofed and paved areas of the city and wastewater is lost quickly without reuse.

Polluted water should not be allowed to cross these vital lines to destroy the sanctity of the common waters of the land and to upset the great balancing medium of earthly life - the seas.

The Geography, Geometry and classification of farm waters, together with the planning and design principles, soil building and the constructional techniques on which they are based, are all fundamentals of the ’Keyline’ plan.

In the design for environment submitted below, the proposal is for water, when finally moves off the land surfaces should do so through ’strip forests’ on farm and grazing lands; and through the ’City Forests’ of towns and cities. In the soil of these forests the water is cleansed and reconstituted.

When we protect the vital line of land’s contact with water the battle of water pollution will be quickly won and there will soon emerge landscapes of unparalleled efficiency and beauty.

III. DESIGNING FOR ENVIRONMENT

If there had been no primary valleys there would be no primary ridges and the main ridge would be the only shape in the landscape. It would stretch from creek to creek and the creeks would be its boundaries. The formation of primary valleys in this one massive main ridge shape gave the land three shapes and assisted in making three landforms. The primary valleys provided higher gathering places for water and higher sites for storing it, below the amphitheatre where the three shapes unite and where water continues its attack. This is the place where the landscape can be made stronger, the focal point for improvements to be carried forward - the Keypoint for landscape design.

The first objective of landscape design is the control and better use of the water that flows over the surface of the land to the watercourses. This is achieved simply by the addition of two new water lines to the landscape. The first water line is for the better control of water; the second is for the improved use of water.

The first water line is a diversion channel to control the run off water from rainfall; the second new water line is an irrigation channel from which to water the land.

These two new water lines are different from the two natural water lines. Where as the natural drainage lines and water-divide lines do not touch, the new water lines cross over the drainage line of the primary valley and the water-divide line of the primary ridge and main ridge. They may also intercept the drainage line of creeks and streams. They may thus connect up two or many unit-regions.

A. The Keyline Scale of Permanence

This concept helped solve problems of priority in the design of the farm landscape. The Keyline Scale of Permanence is an order for planning based on the relative permanence of the various items, which together make up the completed landscape. It can be successfully applied to the design of the town and city landscapes.

The Keyline Scale of Permanence is:

1. Climate 2. Land shape 3. Water 4. Roads
5. Trees 6. Buildings 7. Subdivision 8. Soil

The first two factors climate and land shape are the more or less unalterable background of the landscape. Water, with its lines and its pattern of flow is the first factor of the landscape design that we can change.

The two new water lines added to the landscape have a fall down the land - in the same way the creek falls - but their gradient is made less than that of the creek below. Therefore the further the two new lines are extended, the greater the height difference between them and the creek below, and progressively more land lies between the new water lines and the drainage line of the creek.

Water is thus retained at higher levels on the land. Before it may join the watercourses to flow on to the sea, it must flow over the surface or go through the soil of the landscape.

The new water lines for city, as well as for farm, are permanent features of the designed landscape. All factors below them on the scale are made to fit in with these new but permanent water lines.

The fourth factor is roads. These logically fit in with the new water lines. A road follows alongside the diversion channel right through to the boundary. The diversion channel with its associated road, has now added a ’zone’ to the land by dividing the main ridge and the higher parts of the primary ridges - the high catchment area -from the rest of the land. Another road follows along the crest line of the main ridge to service this zone. The sites for shelter trees (the fifth factor) and for buildings (the sixth factor) with their work areas are positioned in this first zone of the land.

The line of the irrigation channel, which likewise, with its service road, divides the region from end to end, adds a second zone. The second zone is thus bounded by the diversion channel above, the irrigation channel below and the boundary fence at opposite ends.

The land, which contains the areas for irrigating, thus lies in another zone - the third zone of the land. This zone has a lower boundary; a channel; which controls the final overflow of water when it is in excess of the capacity of the soil and the storages.

The land lying between the lower boundary of the irrigation land and the creek is yet another zone, the fourth zone of the land.

The four zones, with their service roads are connected. The site for this road is along the divide-lines, or centre lines, of the one or two large primary ridges in each unit-region. A primary ridge usually has a more or less uniform slope from the main ridge through to the creek below.

The system of new water lines and their roads has not only added four zones to the regions of the landscape design in nature; it has divided those zones in either two or in three parts by the one or two roads which connect and go through them. This further division of the natural regions provides the basis for the complete subdivision of the farmscape, or the cityscape - the seventh factor of the scale.

The fifth factor on the scale of permanence is trees.

Trees are absolutely essential for the health, the balance, the efficiency and for the aggrandisement of all the special purpose landscapes of man, so trees and millions more trees are essential for the total environment.

They must be planted or ’left’ in the right places. A plant, or a tree in the wrong place is a weed.

In the farmscape some trees will be associated with the layout of the new water lines, the roads and the fencing of the new zones. They are planted or left in the initial clearing of the land - to shade the stock and to break the winds, which dry, out the land. They provide in their leaf fall the elements from deep down for the balance of the soil. But in the landscape design, trees have another and special province. The strip forest for the farm and the ’City Forest’ for town and city, protect the natural drainage lines and the seas from the waste products, which may remain in the water that flows from the land.

The strip forests of the farmscape are located principally in the fourth zone of the land. All water that may flow overland from the three higher zones is directed automatically into them. The water is absorbed into the deep soil of the strip forests and is cleaned and reconstituted before it flows to the streams.

All primary valleys or perhaps most of them do not posses suitable sites for storing water at their Keylines; the shape of the valley must have economic and practical significance for the purpose. If three primary valleys of a series in the one main ridge system have good water storage potential, this consideration governs the position of the diversion channel. Because main ridges have a general rise toward the top of the region, the primary valleys tend to have a progressively rising relationship. In the opposite direction -with the fall of the creek - it is a falling relationship. To develop the potential it is wise to compare the relative heights. The reduced level[1] of the Keylines of the selected primary valleys are determined so that the one diversion channel may be designed to fall into the first storage site and continue beyond it to connect up with the other two sites. In this way the overflow (spillway or by-wash) water from the highest storage dam follows the diversion channel to help fill the dams further on down the channel. In like manner the second new water line - the irrigation channel - connects up from dam to dam. When there is more water to be stored and more sites needed for storing it, the diversion channel and the irrigation channel are repeated and connected up the new storages lower down in the primary valleys. Zones two and three are then repeated above zone four.

The country has not been divided along the natural water-divide lines or according to the unit-regions, the twin regions and the larger regions in nature. Boundary lines of farms generally cut across natural unit-regions since so many have been determined with a straightedge on paper. Thus landscape design in not simply a matter to be applied only within the boundaries of the natural regions of the land, but within the constraints of boundary fences.

For instance, the higher boundary of a farm may start on a main ridge and divide a unit-region by crossing over a creek and the main ridge on the other side, and may include the head and one half of the next unit-region. The property may already have a good boundary fence, many subdivision fences, and a stock dam in each paddock, roads through the farm, a homestead, other building and work areas. Moreover it may have been over-cleared of timber with trees left only in the steep places or standing in the “back paddock”.

Of the development work that was put in over the course of many years, only the boundary fence may be correctly located. There is a good chance also that the homestead - the sixth factor of the scale - is well positioned since this is often decided by the womenfolk. Because they like to overlook the entrance to the farm and the work areas, the homestead - more often than not - is located on a main ridge or on the higher part of a primary ridge.

To redesign such a farm the same two new waterlines dominate the plan but there are several considerations that may determine their location. For instance on this particular property the water to be controlled does not all fall as rain on the farm, since, as one boundary fence crosses a region, water from outside the farm flows in, via a creek. This source of water may be greater than from rain falling on the farm itself.

Design starts with the control of the water of greatest landscape significance. This is invariably water of greatest quantity and lowest cost.

Firstly, the entire property is examined to determine the water resources available, to pinpoint the features of the landscape and to envisage and decide on the landscape design for the farm.

Secondly, the most advantageous place for a starting-off project is selected. The prime requirements are that it fit the landscape design and be of such significance that it will quickly enhance the overall production and value of the farm. It proceeds by progressively controlling all the water resources that have profitable significance.

While these principles of design are universal in their application, there will be only one way to design each landscape. Every special purpose landscape will be unique; there will be no other like it on the face of the earth.

The last of the eight factors of the scale of permanence is soil.

Natural soils were not always fertile but when soil was fertile it was a great storehouse of the renewing and renewable resources in Nature. In the fertile natural grasslands and nearby forests, all the life in the landscape lived in the natural recycling processes. This is the interaction of life with air, water, rocks, earth, the heat and light of the sun through time. Life has lived, bred and died for countless generations yet the abundance in nature remained intact. This is the balance of the landscape.

The history of mankind in his series of leaps and retreats type of conquest of the earth, is the story of his discovery and exploitation of the great abundances of Nature held in the soil and in the earth.

A fertile natural soil may be deprived of its fertility surpluses in a few decades as the various races of man have ably demonstrated over thousands of years.

However impoverished soil can be made fertile again and soil which was originally of low fertility, can be made deep and fertile -both in a short space of time.

The management of this design for the farmscape is concerned with the improvement of the fertility of the soil. Therefore it is concerned to see that all the wastes of the farm from plants and from the urine and dung of the animals is absorbed again into the soil where it rightfully belongs. It is concerned to see that water, which leaves the farm, does so by first being absorbed into the soil to improve it, so that, as a coincidental, nothing from the farm may pollute the common waters of the land and the seas. The management of the design for the cityscapes and for all the special purpose landscapes of man is likewise concerned with these same matters.

[1] Reduced Level (R. L.) When surveying to compare the elevations or heights of points of interest the various readings are reduced to a common base height. This base may be mean sea level but, more commonly, it is an arbitrary number large enough to avoid the occurrence of negative values in the results. The starting point of a Keyline survey is common given a R. L. 100.00 value. Editor.

IV. BASIS OF KEYLINE LAND PLANNING

In order to plan any development or improvement of agricultural land, or land for an agricultural purpose, it is necessary to know just what is required of it. Is it to:

(1) Eventually show the most profit?
(2) Be the best possible under the circumstances?
(3) Some other important objective?

Even with some other important objective points (1) and (2) must come into the picture somewhere.

The planner must know what the particular area is capable of becoming. In other words there must be a capacity for assessing the development potential of the particular area.

Points to consider include:

a. What constitutes the potentials of land?
b. How can these potentials be discovered and assessed?

Not until satisfactory answers to these two questions are known is one in a position to begin to formulate a plan.

The potentials of land comprises those things which largely determine the land's value, the value being the price it will fetch on the open market at any particular time. One class of these potentials does not depend directly on the specified area itself but relate to outside influences, such as the market prices for the products that will be grown on the land. Other values of a similar nature relate to the locality of the farm; to the distance from a town and whether or not the town is progressive and expanding; to the conditions of public roads, and to the community facilities that are available to the farm or grazing property.

The other class of potential, and the one which concerns these assessments for improvements, is influenced by such factors as the type of land, whether flat, undulating or hilly, the soil and the rainfall, and other aspects of climate.

The maximum of these potentials of any piece of land depends to a great degree on the capacity of its soil for improvement, and ultimately the principal means of improving the soil lies in man's own capacity to control the water and air within the soil.

Much new land in Australia is brought into agricultural production by first clearing it of scrub and timber. If it is to be used for pasture production, grasses and clovers will then be grown by any of several methods which, with the kinds of seed sown, will usually follow the pattern of the district. If crops are to be grown, then the first crop may be a “cleaning” crop such as oats, which again will usually follow the general pattern of the district. But these improvements, plus the usual subdivision fences, are not those that use the full resources of the land. Indeed in this ordinary means of “bringing in land” these potentials may be little utilised since they seldom use, even to moderate advantage, the water available.

A. The Geography of Keyline

As an aid to the assessment of the water resources of land, which plays a principal part in soil and land development, the Keyline classification of the shapes of land will be presented. These features of the land are somewhat dominating in their influence on water movement and on the means for its control and use. It will soon be seen that land cannot be classified without continuous reference to water, the subjects of land shape and water being nearly inseparable.

To begin with, the settled shape of agricultural land, with its rounded and smoothed out ridges and valleys is a water shape. No matter what its basic geology, the finishing touches to the land shape have been imparted by the climatic elements, especially rainfall and flowing water. Vegetation and soil organisms provide a stabilising effect.

The two principal “lines” of any agricultural land are water lines. These are, firstly, the *stream courses* of every size and, secondly, the *ridges* that divide the rainfall water which falls and flows to the valleys and streams on either side of them.

Water is thus divided by ridges to concentrate as streams in valleys.

1. Primary land forms

The stream courses naturally follow the bottoms of valleys which flowing water has formed and, just as stream courses have other streams flowing into them, so also do valleys have other valleys flowing to and joining with them: all except one type of valley. This is the “primary” valley of the farm and grazing lands, the first land shape of Keyline. This valley starts or heads in a ridge and sheds its run-off rainfall water to the stream course below.

The two “shapes” or “forms” of land. There are “ridge shapes” and “valley shapes”. Practically all agricultural land holdings are either one of these two shapes, part of one or both, or contain one or more of either or both of them.

a) The main ridge

A good starting point from which to consider the primary land forms which are significant to agriculture, is the junction of two water courses. The water courses may be permanent streams, perennial streams or intermittent water courses. From such a junction and looking upstream, the land between them will contain the line of a water-divide or a water parting. This is the main ridge of the ’Keyline’ classification of land forms. Run-off water, provided by rainfall, from the land between these two water courses will be divided by this main ridge line and flow to its respective stream. Again, along this water line divide, water falling as rain only centimetres (inches) away on either side will flow in opposite directions. The water-divide line that lies along a ridge shape may join up with other main ridge lines, which also are water-divide line or water-shed separating lines.

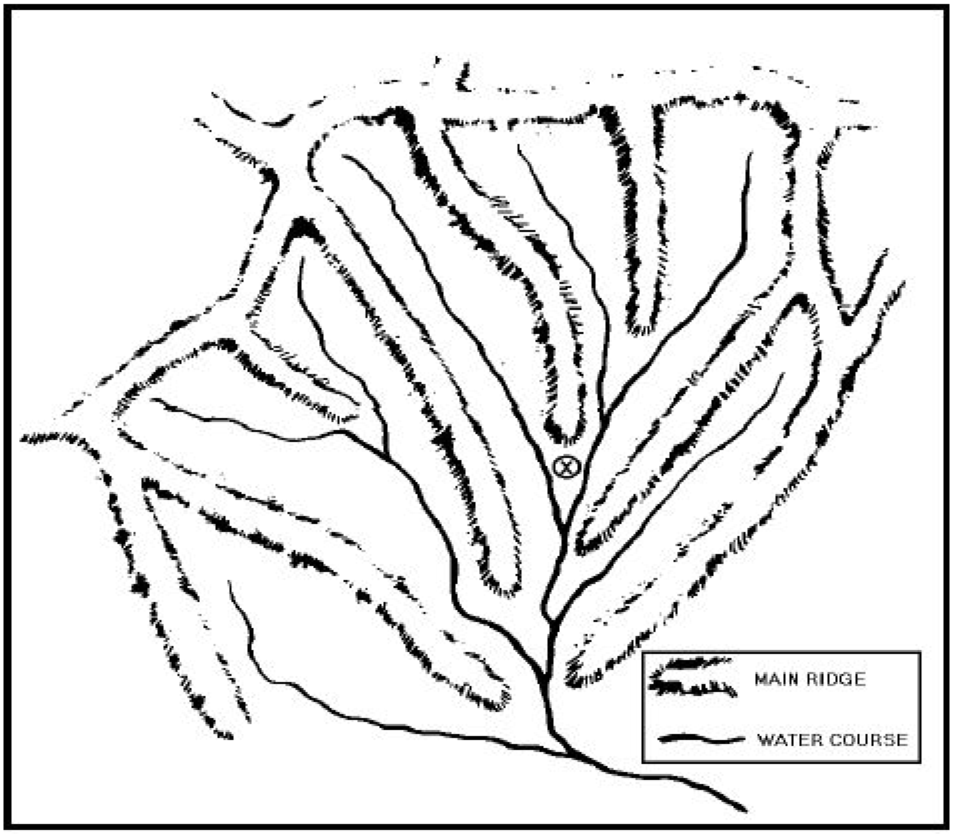


Figure 1 The branching pattern of the 'main ridge' is similar to that of the water courses.

The main ridge of the ’Keyline’ classification of land forms and all similar ridges, no matter what its size or shape, are likewise always classed as ’Main Ridges”.

A main ridge has its start between two adjacent streams and at the junction of them. It always joins up with another main ridge at its upper limits and thus becomes a part of, with still other main ridges, a continuous water-divide. The line of a main ridge is not always rising (increasing in elevation) away from the junction of the streams below it. Often when two main ridges join, they form a hill and the main ridge may then descend to a saddle before rising again. Each low point along the line of the main ridge is called a *saddle*. A hill is simply the high point or rise before the saddle on a main ridge. Along any main ridge, saddles will always separate the hills.

The connecting patterns of the main ridges is continuous in a manner similar to that of the persistent branching and joining designs of the streams and rivers. So much is this so that if a hollow model of undulating land were turned upside down, the new land form thus depicted would show the stream courses as now the main ridges, and the main ridges as the stream courses, and with their appropriate joining or branching design. Hills become lakes and lakes hills. Saddles become the overflow point of any lake.

The main ridge lying between two adjacent water courses is the dominating land shape in the Keyline classification of the topography of farm and grazing lands.

Just as nearly all land may be said to lie between water courses, so all the shapes of land lie between water courses, and are therefore closely related to the main ridge. This holds good for all types of land in all types of country.

b) The primary valley

Moving in the upstream direction along the main ridge, a succession of valleys separated by smaller ridges, fall from the main ridge and on both sides of it toward the appropriate stream course below. These valleys are the “Primary valleys” and the ridges, the “Primary ridges”. (See figure 2.)

A primary valley head generally starts as a more or less sudden steepening of the side slope of a main ridge. Further down, the valley changes to a flatter sloping floor which continues more or less uniformly to the stream course below it. The primary valley is the smallest of the valleys of land and unlike the valleys belonging to creeks and rivers, does not usually have a washed out or channelled water course down the middle of it unless erosion has taken a toll.

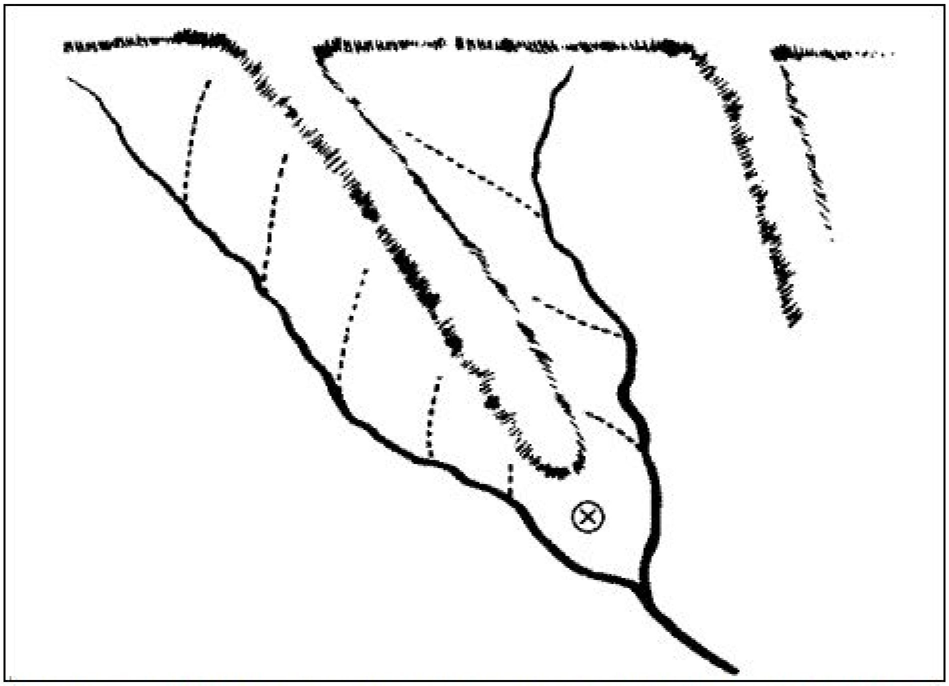


Figure 2 The land between two creeks showing the 'main ridge'. The dotted lines are the centre lines of the two series of 'primary valleys. Between the primary valleys lie the 'primary ridges'.

Rain falling on the main ridge and in the vicinity of each primary valley is concentrated by the valley shape and finally flows down the smooth and rounded valley bottom to the channelled stream course below it.

c) The primary ridge

On both sides of each primary valley lies a primary ridge. The two primary ridges appear give the primary valley between them its valley shape form. However it needs to be appreciated that the primary ridges are the relatively undisturbed portions of the sideslopes of the main ridge. The primary ridges are the ridge shapes remaining after the primary valleys have been scooped out, as it were, in the sides of the main ridge.

Referring to Figure 2, X is the start of the main ridge as discussed. The hatched lines illustrate the branching and joining pattern of the water-shed or divide lines and therefore of the main ridges. The unbroken lines are the stream courses and the dotted lines represent the centre line of the primary valleys of this lesser water-shed. The primary ridges lie between these dotted lines.

These are then the principal landscape classifications of Keyline: (1) the “main ridges” from which form (2) the “primary valleys” which are divided by (3) the “primary ridges”.

d) The secondary valley

On occasions a series of primary valleys on the one side of a main ridge will join up with a larger valley which does not contain a channelled water course in the bottom of it. Such is named a “Secondary” valley, and it will have at its commencement its own Keypoint and Keyline.

The land which may lie between two such streams as in Figure 1 may vary widely in area. Rainfall and the degree of slopes of undulating country have a very considerable effect, and generally the area will be smaller in the wetter, and larger in the drier zones.

For these reasons one or more main ridges or parts of them with their primary valleys and primary ridges may be present on the one property, while another of equal size may only include a small part of a main ridge and one or two primary valleys and primary ridges; or again a property may contain only a portion of one of these lesser land forms. However because the size of these land units usually relates to the annual rainfall, with the smaller units in the wetter areas and larger in the drier areas, and since the general size of farm and grazing holding rises as the rainfall decreases, the general order is that several of all the forms exist on each property. There is thus a need to devise planning relationships between the various groupings of these land forms.

These classifications of land forms are according to their *shape* and not to their *areas*. Thus it will be seen that yet other pertinent descriptions of land may be defined. Land can be said to have “length”, which would be from the water-divide on the main ridge to the stream course below. This length-of-land may be as “short” as half a kilometre (one quarter of a mile), or “medium” as one to two kilometres (one half mile to a mile), or “long”. “Long” or long-slope country may range up to several kilometres (some miles) from the top of the main ridge to the stream course below it. Coupled with the length of land, slope of land may be designated. This land-slope again relates to the main ridge and to the stream course below it.

2. Location of “Keylines”

Reference has been made already to the two slopes of a primary valley: from the higher slope of the main ridge, the primary valley forms with a first slope which may be short in respect to the full length of the primary valley. This first slope of a primary valley is steeper in relation to the second longer and flatter valley slope. The Keypoint of the valley is the point of change in the two slopes of the primary valley, and a contour line from this point and in both directions within the valley is the Keyline of the valley. It is worth emphasising that the Keyline does not extend onto the ridge at all. A Keyline only exists as a feature of a primary valley.

The name Keyline, coined to describe this contour line, has also been given to this full system of land development.

A primary valley, bounded by the portion of the water divide of the main ridge above it and by the water-divides of the primary ridges on either side of it, is the primary, the smallest, or the first catchment area. Likewise the valley or the drainage area of a small creek would be bounded by the water divides on the main ridges on either side of it, and by the portion of the upper main ridge which is joined by these two. These distinctive drainage areas progress in size until they eventually embrace the complete water-shed of the largest river systems to which all the waters flow.

Now while it is customary to classify, plan and develop great tracts of land for Governmental purposes according to these drainage areas of the larger river systems, this should not apply to smaller developments. The subdivision, the planning and the development of land for the individual farming and grazing holding should not be according to their lesser drainage areas. For instance in the development of farm water resources it is often of great advantage to inter-connect the smaller drainage basins by diverting run-off rainfall from one such drainage area for storage in another one. Similarly, in the working of land with cultivating and harvesting machinery, water-divides are often crossed over. Therefore the more suitable boundaries for both general working and for maximum development are those of the water courses themselves.

a) The rising relationship of Keylines

The above fact may be further illustrated by considering the water position in two separate areas. In the first instance, all or several primary valleys falling from the one main ridge to the creek below may be contained on a property where, while the rainfall is in the order of 500 to 1000 mm (20 to 40 inches) per annum, there exists at frequent times both intermittent water shortage, and later on, considerable rainfall run-off.

Primary valleys on undulating land contain suitable sites for water storage but these sites may not have satisfactory natural catchment areas. Water may be diverted from one or several primary valleys to fill a dam constructed to receive the water.

The highest site for a storage dam in a primary valley of good shape for this purpose is just below the Keyline of the valley, where the wall for the dam would cause the water line of the dam to coincide with the Keyline of the valley. These may be called Keypoint dams.

The Keypoints of a series of primary valleys along one side of a main ridge have a rising relationship one to the other as the main ridge rises from its start at the junction of two water courses. The Keylines of such a series of primary valley will also have the same rising relationship.

Some of these valleys may be suitable for Keypoint water storage and these dams may be inter-connected by channels. The channels will divert run-off water sideways across the landscape and as each dam fills the overflow continues along the channel to fill other dams in the series.

The Keylines of the primary valleys may not, on the other hand, be suitable as dam sites, but the same type of inter-connected series of dams may be suitably placed at a somewhat lower level. As long as the channel connecting the series of dams has a gradient which follows the fall of the land at a lesser grade than that of the stream course, the succession of dams will generally have progressively more land below them which may be irrigated by gravity flow.

As a general rule, the direction of the flow of diverted water on farms and grazing properties should follow the general fall of the land. This direction is clearly shown by the fall of the water course below.

In a second instance of water diversion from the one catchment through other catchments on a farm occurs when considerable water from run-off rainfall enters the land via a small creek. There may be a good dam site near the entry of this water to the property, and yet there may be even more water available than the storage near the creek’s entrance will hold. This water may then be diverted through a whole series of primary valleys for filling storages constructed only in those valleys where there are suitable sites for dams. An example on these lines is also illustrated on the aerial photograph of “Yobarnie” Plate 2 and in the plan of the property in Figures 3 and 4.

The entrance of the small creek with its relatively small diversion dam is to be seen on the western boundary. The diversion channel from this dam fills in succession, four more dams. Note the increasing distance of each of the succession of dams from the creek which feeds them; note also the increasing areas below each of the dams and the creek.

b) Contour maps for land planning

These shapes of land and their water relationships are considered to be of paramount importance as basic elements of land planning. A quote from Chapter 2 of “The Geographical Basis of Keyline” by J. Macdonald Holmes, states:

> “Not only must land scientists and farmers have an eye for country, they must also ’see’ their land on paper, since working on land and planning on paper must be performed together systematically. The best way to show land shape on paper is by means of a contoured and scaled map. Contours on paper represent horizontal lines on the ground, or better still, outcrops of horizontal surfaces on a slope. They also denote heights above some fixed base level, usually sea level. Contours marked out on the ground would be level lines. On paper they would twist and turn, depicting valleys and ridges, steep land and level land.
>
> One can appreciate the shape of land from a suitable contour map of the land much better and more readily than one could from an examination of the land itself. Although these lines appear to be indiscriminately spread, this is not so. They follow very definite natural patterns. Within the pattern of these contours lie some of the secrets of Keyline”…

As Professor Macdonald Holmes says, the best way to illustrate land on paper is by means of a contoured and scaled map (called a topographical map). The “contour interval” which is the distance apart of the contours vertically, should be suitably selected to disclose the shape and form of the particular land. The scale should be suitable for planning.

Indeed, with the aid of such a map of an individual property, an experienced Keyline planner could lay out a working specification covering the full development of the property, provided that he had a good knowledge of the climate and that the landowner was available to give details of the soil and other materials necessary for the planner to know in respect of particular locations on the land itself.

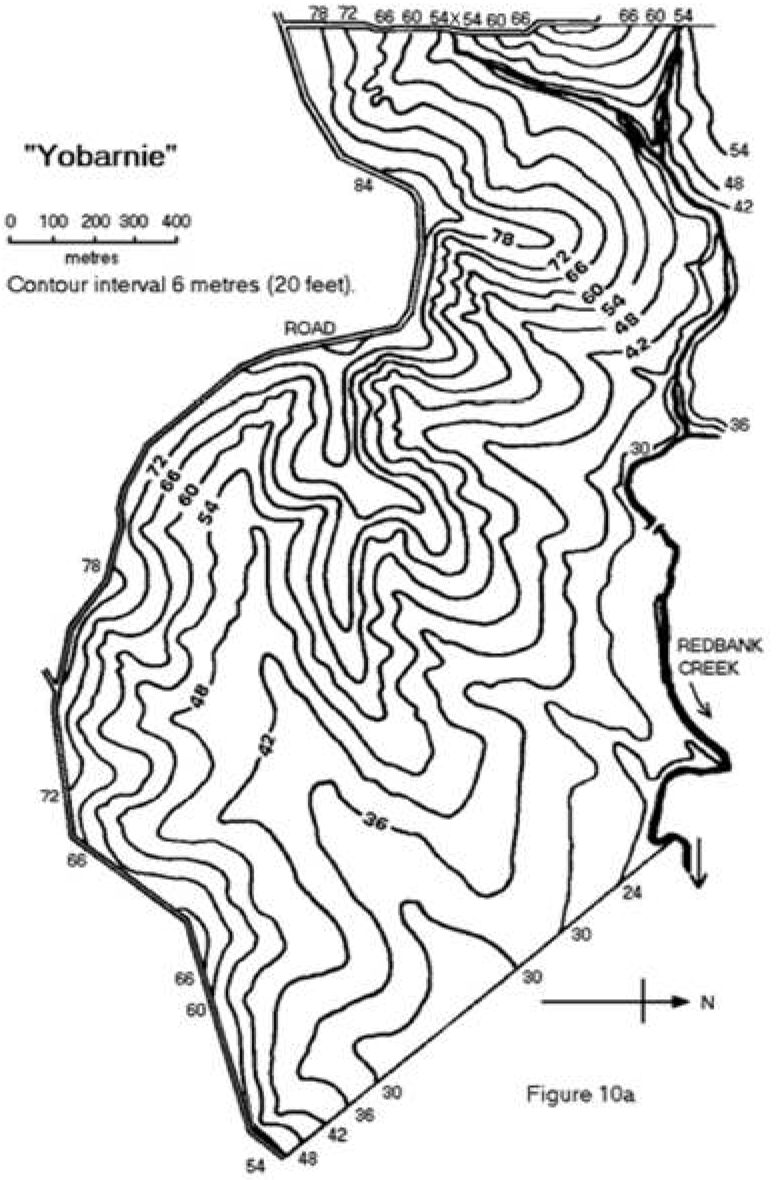


Figure 3 Contour map of most of Yobarnie. The road to the left follows a main ridge. A creek enters at **X**, top middle. The primary and secondary valleys and ridges fan out towards the right from the main ridge. Contours are 6 metre intervals converted from original 20 feet contours.

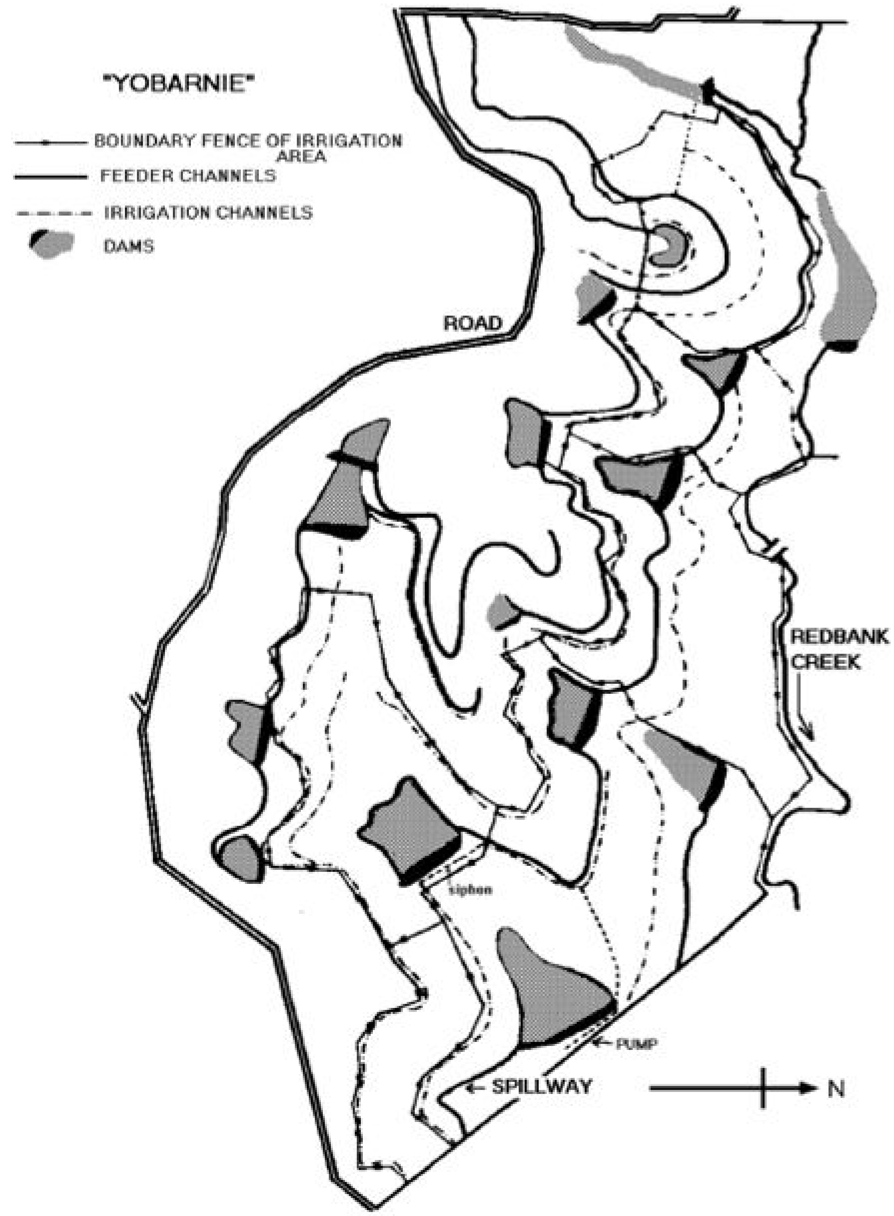


Figure 4 The flow through the spillway of the creek dam fills six other dams below the creek diversion channel. Pumping is only from the lowest dam on the bottom boundary.

Suitable contour maps enable such plans to be produced in ample detail to include:

1. the location and size of water diversion and irrigation channels and the position in respect to these works of possible irrigation areas. The type and location of water storage, selecting the most suitable capacity and

wall heights of these structures. Even the appropriate irrigation procedures could be designated.

2. farm roads,
3. the areas to leave trees already on the property or positions to plant them,
4. the sites for farm buildings,
5. the placement of subdivision fences and stock working paddocks and stock watering points.

All of these could be decided quite competently without this designer of land development actually seeing the land itself. This plan could then be transposed onto the land either project-wise or piece by piece as circumstances may permit or dictate. Such is the great value of good contour maps!

The next two figures are maps of our former property “Yobarnie”, North Richmond, about 80 km West of Sydney in New South Wales. The contour map enabled the creation of the development plan for the property. The contour map reveals height and distance relationships essential for planning.

Plate 2 An aerial photograph of "Yobarnie" showing the same area depicted in Figure 3 and 4.

B. The Geometry of Keyline

We may now proceed to further illustrate, by means of contour maps on the following pages, the various land shapes and relationships already described, to show the principles of the intimate relationship of the contours of the primary land forms and their uses as disclosed in the "Geometry of Keyline".

Figure 5 and 6 below, shows a portion of a main ridge which has two primary valleys and primary ridges on one side of it, falling from the main ridge to the water course below. The general fall of the land is seen in the direction of the fall of the creek. The slope of the land, the cross fall from the main ridge down the primary ridges to the creek below, is indicated by the arrows on the primary ridges. This is also the "length" of the land. The Keylines of the various primary valleys are marked by a thickening of the appropriate contour line to illustrate the rising relationship of them.

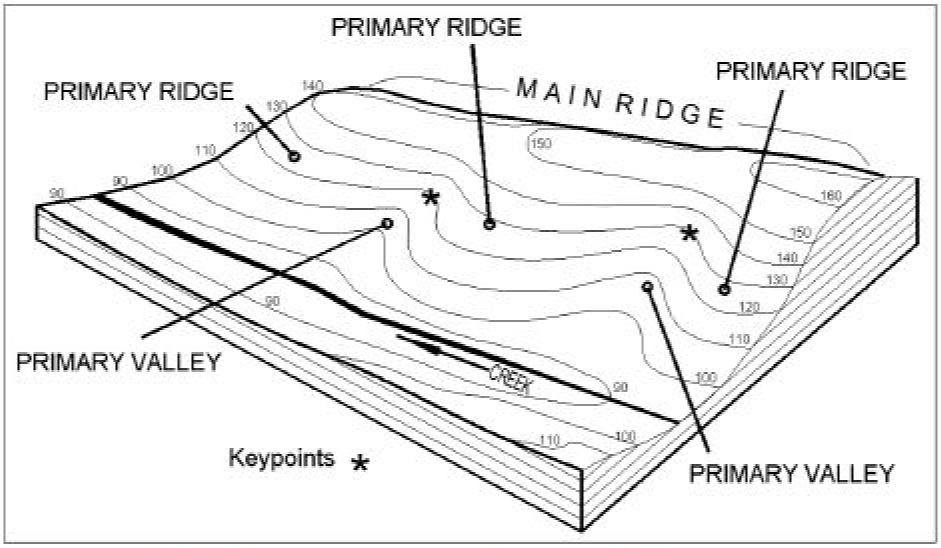


Figure 5 This figure is a perspective view showing how a contour map relates to the landscape. The figure was developed from one in Prof. Holmes' "The Geographical Basis of Keyline" (out of print). Shown are the main landscape features named in Keyline.

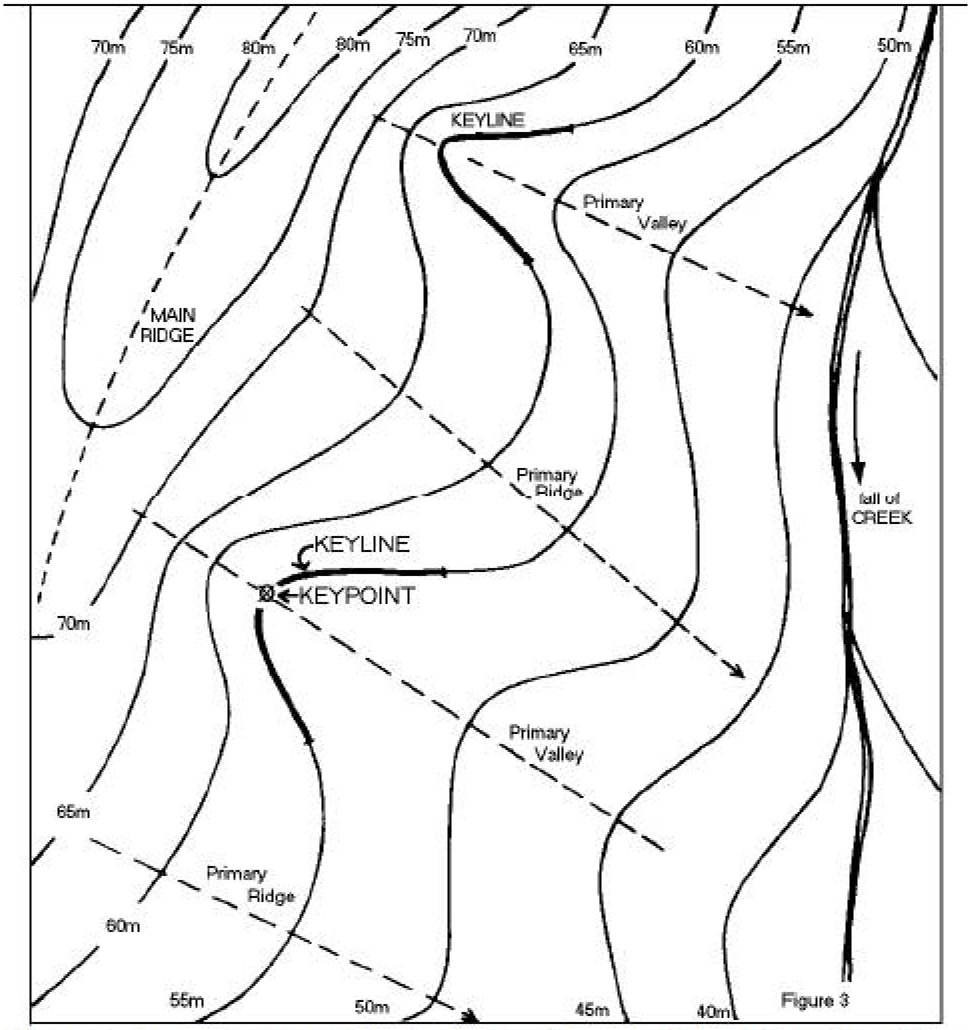


Figure 6 A contour map showing two primary valleys falling from the main ridge to the water course below and with a primary ridge between them. Note the limit to the length of each Keyline and that they are not on the same contour line.

The next diagram, figure 7, shows the more intimate contour relationship between a primary valley and a primary ridge. This is a somewhat normalised contour diagram and the relative size of the primary valley, is enlarged for clarity. The contour lines show the changing grade of the primary valley. Being closer together at the top of the map indicate the upper slope of the valley is steeper.

Below the Keyline, a wider interval between the contours indicates the flatter valley floor below.

In the primary ridge portion of this contour diagram the distance between of the contours illustrates that the centre of the ridge is comparatively flatter than the sides of the ridge towards the valley. This is the typical shape of a primary ridge. Flat down the middle and steeper on the sides.

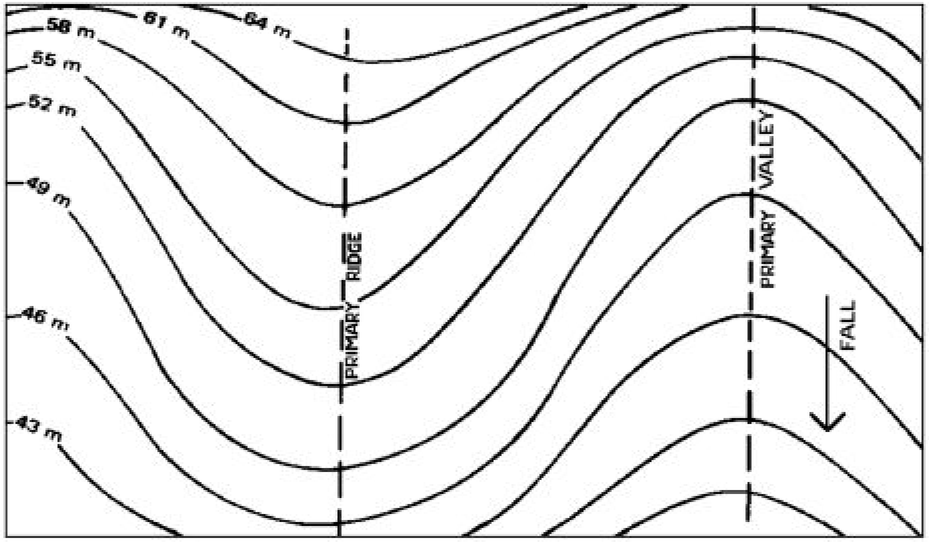


Figure 7 A contour diagram showing a primary valley and a primary ridge.

Note that the contour lines converge (get closer together) as they move from the centre of the primary ridge toward the valley. The lines get closer as the country becomes steeper moving around towards the valley. Initially all the lines are curving in one direction because they are wrapping around the ridge. The lines then change direction depicting the shape the valley. After they change direction the contour lines will continue to converge if they are above the Keypoint of that valley. However if they are below the Keyline the contour lines will diverge (get further apart) after they change direction.

1. Flowing water makes its own pattern.

Water during very heavy rainfall will be moving over practically all the land surface at the one time. The contour diagram of figure 7 is repeated in figure 8 to illustrate the pattern of water flowing in respect to the contour shape of the land. Water follows the steepest path downward to the valley below which is at right angles to the contours, being the shortest distance and the steepest path. The water in effect continuously adjusts the direction of its downward path resulting in a general flat S bend shape.

The natural result arising from this movement of water is that from the time the rainfall produces general run-off the land is not “watered” evenly.

One effect apparent later in drier weather is the greener valleys and the drier ridges.

The contour diagrams below portray the pattern of water flow from ridge to valley and Figure 9 illustrates the accumulation and increasing flow from ridge to valley.

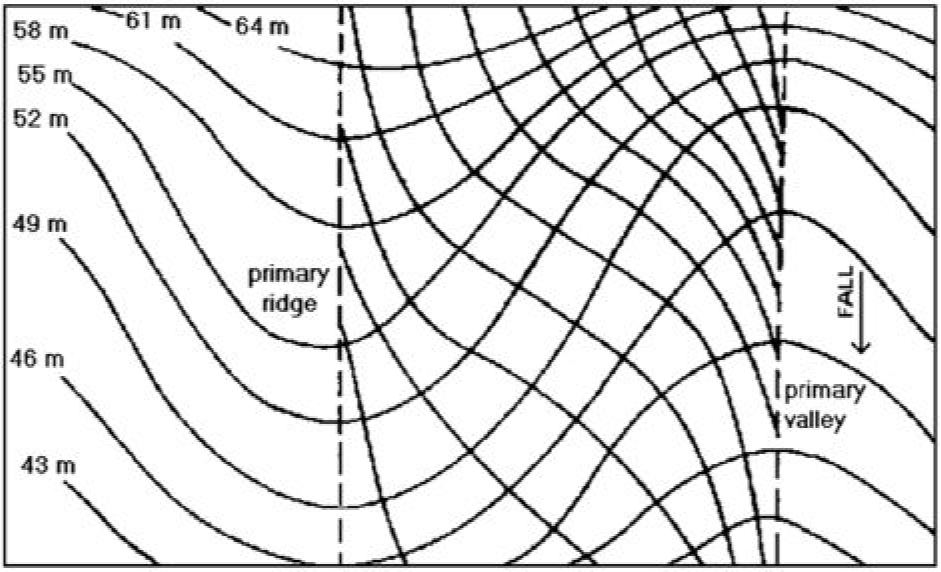


Figure 8 The flow paths of run off water from the ridges to the valleys are flat S curves.

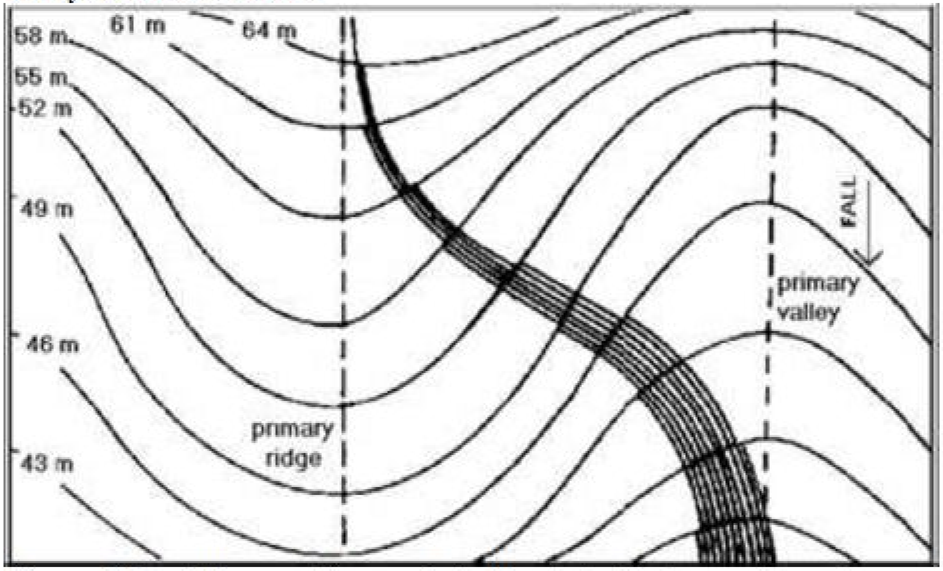


Figure 9 Depicting one flow path to illustrate the increasing volume of flow from the ridge to the valley

V. KEY LINE PATTERN OF CULTIVATION

The objective of the pattern in Keyline pattern cultivation is to direct the shallow overland flow, which results from rainfall run off, to remain evenly spread and not follow its natural flow path to concentrate in valley shapes. The same technique also provides the means for evenly spreading the water in the system of "hillside" irrigation named "Keyline Pattern irrigation". It is the Keyline pattern cultivation that can convert what is commonly called "wild flooding" into fully controlled irrigation.

The technique of pattern cultivation or "pattern ploughing" takes a selected *section* of a contour line as a guide and proceeds by working back and forth either up the slope or down the slope, according to circumstances, parallel with this contour.

The next few paragraphs reveal a little of the context in which this cultivation pattern discovery was made.

In our first attempts to use for irrigation the water which was in such a hurry to get off our farm; costs, in time and money, were prohibitive. We were not looking to irrigate a potato patch or a few acres of grass, it had to pay for growing beef; so all the water available was needed and it first had to be stored in dams. There were no difficulties building them; that was already an experience in mining work.

At that time (1940s) government departments showed little interest in farm dams for irrigation. Critics described our dams as huge and useless. They said our soil was no good for anything and why cover with water the little good soil we had in the (primary) valleys in order to irrigate worthless shale ridges? Only creek and river flats were worth irrigating!

Such opinions were universal then, but passengers flying southwest of Sydney Australia today will see evidence of the reversal of this view in the concentration of these dams so close to the metropolis. All were constructed years after we established their practicability and they are for irrigating land formerly believed unsuitable for the purpose.

We used both flood and spray systems of irrigation. The rate of water flow was doubled from 30 to 60 litres per second (25,000 to 50,000 imp. gallons an hour) which was more than double spray rates at the time. However, the money still flowed the wrong way.

While new ideas for irrigation were constantly being tried other experiments to improve soil were going forward. In theory and on paper a way had been devised for cultivating the land to slow down the run-off rainfall. It would retain the water on the primary ridges and actually drift it toward the centre of the ridge. In the primary valleys it would make the water drift outwards from the centres of the primary valleys. It was called Keyline ’pattern’ cultivation, and now we would try it out.

Forty hectares (one hundred acres) of dry land were ploughed (ripped) to the ’pattern’ with an implement half way between the later chisel plough and a road ripper. Some months later, during a weekend stay on the farm, it rained and an inspection was made of the ’pattern’ cultivation. Upon entering the paddock it looked good. The rain was heavy, the run-off was held up nicely and spreading evenly and not concentrating anywhere. A dam some distance away was overflowing down a small primary valley. This water was also doing exactly what in theory it had to do yet it was absolutely astonishing. Instead of flowing as it would normally do, about 3.6 m (12 feet) wide, 300 mm (a foot) or more deep in the centre of the valley and fast, the ’pattern’ had taken complete control. The sheet of water was flowing 54 metres (180 feet) wide, covering from boundary to boundary the entire primary valley. The outside edge was 0.9 to 1.2 m (3 and 4 feet) higher than the centre of the valley and was flowing the same depth as in the valley bottom. There was a flow of water ten times greater than we had used (for irrigation), moving uniformly downward over a strip of land which sloped in three different directions. Keyline ’pattern’ was a breakthrough!

Keyline pattern irrigation is based on pattern cultivation which in turn is based on the pattern of the contours of the various shapes of the land. Contours, which by nature are a uniform vertical distance apart, are parallel to each other on the vertical plane only. The contour lines depicting undulating land are not parallel to each other. Therefore if lines are made parallel to a contour on one side of it either on paper or on the land surface, these lines do not remain on the contour but progressively develop a slope as the distance from the initial contour increases. If other lines are made parallel to the same contour, but on the other side of it, they too would develop into sloping lines but their slope direction would be opposite to those of the first group of parallel lines.

When the parallel lines are the hundreds of small furrows of chisel type ripping they will influence run off and sub-surface flows of water to drift according to which side of the particular contour the ploughing has been done. It follows that any cultivation which is done parallel to *any* contour line marked in on the land surface, must inevitably drift off the true contour as the cultivation continues.

This fact is used as a device in “Keyline pattern cultivation” to alter the natural flow pattern of water, which is toward the valley and retain it longer on the ridges, and indeed to “drift” the early flow of run-off rainfall in whichever direction the operator desires it to go. As the flow from rainfall run-off increases, it may eventually reach proportions that overcome the drift of the water that has been induced by the pattern of cultivation, and so resume its natural flow path as illustrated in the previous chapter in Figure 8.

Keyline cultivation has practical and positive application on any of the shapes, or parts of the basic shapes of land. Wherever one wants to spread water uniformly, or to cause shallow flowing water to drift towards the flatter or steeper slopes, the principles of Keyline pattern cultivation can be applied.

The only circumstances where the selection of the correct side of the contour for either parallel upward or parallel downward cultivation is not significant is where the contours form perfectly parallel lines on the land surface. In these limited circumstances cultivation done, on either side yet parallel to the contour guide line, will have a neutral effect on the sideways drift of run off water. Keyline cultivation, or pattern ploughing is illustrated in its application on various land forms in figures 10, 11, 12, 13, 14 and 15.

Figure 10, below, is a contour illustration of a primary valley sloping down to the right with the Keypoint and the Keyline of the valley marked in.

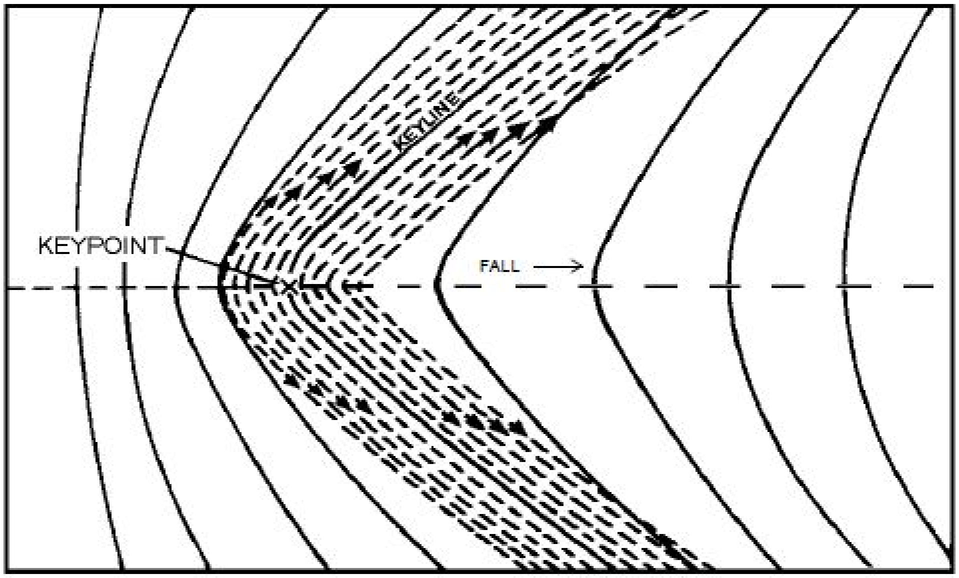


Figure 10 A contour diagram illustrating Keyline cultivation for a primary valley. The broken lines show cultivation parallel to the Keyline both up and down the slope.

A. Cultivation of a Primary Valley

The broken parallel lines illustrate the correct procedure for cultivating this valley area. For the portion of the catchment area above the Keyline, the cultivation should be done parallel to the Keyline on the top side of it. This will achieve the desired water spreading action because the lines representing this cultivation reach the next contour above the Keyline first at a point in the centre of the valley.

The cultivation proceeds up the slope with each successive pass with the cultivation equipment done on the top side of the previous pass. However because the area above the Keyline is steeper than the same height band on the adjacent ridges, the rate of height gain will be faster in the catchment area above the Keyline than the rate of height gain on the flatter slopes of the adjacent ridges. As the cultivation proceeds up the slope a pattern develops in the small furrows formed behind the ripper. This pattern develops progressively and its effect is to lead all run off water downward away from the centre line of the valley and outwards towards the adjacent ridges.

This upper and steeper slope of a primary valley is usually much shorter than the longer flatter slope of the valley which is below the Keyline. In some circumstances this upper and steeper slope may be too steep for the working of cultivation implements. Wherever this slope can be worked, the ploughing can be extended sideways out and across the primary ridges on either side of the valley. The pattern will be maintained so long as the cultivation is done parallel upwards and the water will tend to drift through this pattern toward the centre of the ridge.

Below the Keypoint and Keyline of a valley the cultivation should be done parallel to and on the lower side of the near contour guide line. The Keyline is the highest contour guide line that can be used for parallel downwards cultivation. Here, because the cultivation parallels downward from the Keyline it looses height quickest and reaches the next lower contour first at points out on the steeper valley sides. Again the pattern that develops is such that the slope of virtually all the small furrows is downward away from the centre of the valley, spreading any run off water into a wide shallow stream and away from the centre of the valley toward the ridge. This cultivation of the primary valley below the Keyline need not be continued too far downwards.

Another contour line can be selected for a cultivation guide lower down the valley and the cultivation, then proceeds downward from the new contour guide-line. The area in the centre of the valley above this line, which is not cultivated when the work from the Keyline downward reaches the guide line on the sides of the valley, can be ploughed out by simply lifting the ripper and turning back when the new guide line is reached. Some times it is easier to reverse the tractor back to the centre of the valley, however as the area involved is usually quite small it can be cultivated without any great concern for its pattern.

The Keyline cultivation of a primary valley below the Keyline cannot be extended onto the ridge as can that done above the Keyline. In fact one should turn around and work back around the valley each time one reaches the area of steepest slope on the side of the valley during any pass with the cultivation equipment. The reason for this is that the cultivation reaches the end of the valley shape which occurs at the place of steepest side slope during any pass with the equipment.

Keyline pattern cultivation of a primary valley is done parallel to and on the lower side of the Keyline or any other approximately contour guide line in of the valley area below the Keyline.

1. Tight valleys

Some steep primary valleys cannot be cultivated as described, because the shape of the valley contours may make turns in the valley floor impossible. The contours in the valley bottom will be sharp or somewhat pointed. These valleys are most suitably worked in a herring-bone pattern with tractor-attached rather than trailing implements. The valley is then cultivated in two parts, with the centre of the valley as the dividing line. Cultivation proceeds from the centre of the valley along the appropriate contour working parallel downward as before, completing the cultivation first on one side of the valley, then the other.

Another contour line can be selected for a cultivation guide lower down the valley from which the cultivation will proceed downward from the new contour guide-line. The area in the centre of the valley above this line, which is not cultivated when the work from the Keyline downward reaches the guide line on the sides of the valley, can then be ploughed out without any concern about the pattern.

Between the primary valley and the primary ridge there is an area where the contours indicate a boundary. This boundary lies down the steeper sides of the primary ridges and is shown in figures 11 and 12 on page 69 & 70 respectively.

The cultivation pattern on the primary ridge is best not continued into the valley past this line, for to do so will reverse the water spreading pattern. Sometimes however, with small valleys and or large cultivation equipment it is impractical to cultivate each individual valley working parallel downwards. Under these circumstances the comparatively small area of the valley can be cultivated as part of the general parallel upward working of the surrounding ridge shapes. Upon entering the valley shape by turning the equipment up the valley a little and then back down again after passing the centre line of the valley can help produce a more favourable pattern in these tricky circumstances.

Keyline cultivation of a primary valley below the Keyline cannot be extended out onto the ridge as can that above the Keyline. The reason for this is that the general pattern of primary ridge cultivation is parallel upwards from the selected contours. By wrongly extending the cultivation of the valley pattern, for instance to the centre of the primary ridges, the result could be that the water would first drift out of the valley toward the steeper sides of the primary ridge, and beyond this point the furrows will tend to drift water back from near the centre of the primary ridge toward these steeper parts. Thus water could be concentrated adversely from both directions towards the steeper areas.

B. Cultivation of a primary ridge

The general pattern of primary ridge cultivation is parallel upwards from a selected contour and is shown in Figure 11. One effect of Keyline cultivation is to trap potential the run-off water on the central and flatter portion of the ridge as the following photo shows.

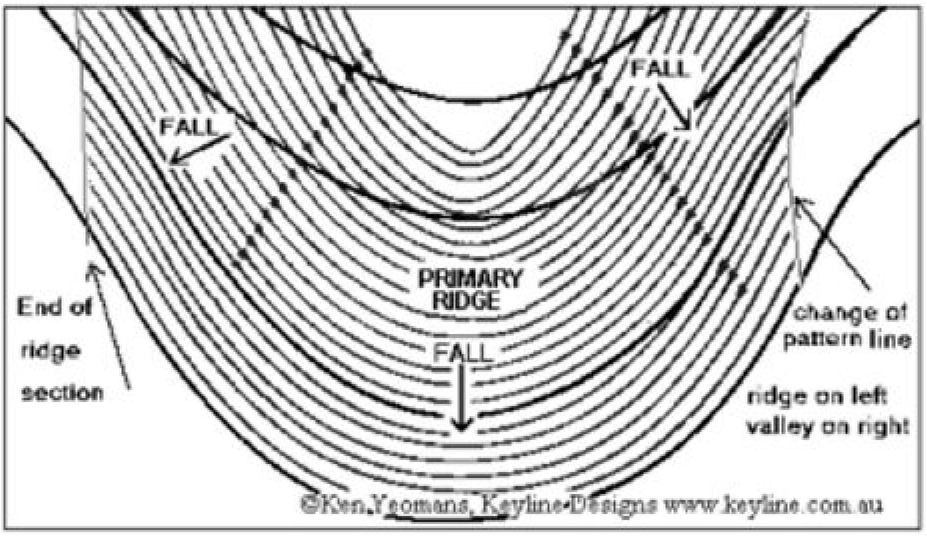


Figure 11 The contour diagram show a primary ridge with Keyline cultivation designed to drift the first flow of run off towards the centre of the ridge. Note the end of the ridge pattern cultivation.

The thinner parallel lines of figure 11 illustrate a cultivation pattern that automatically develops as a result of cultivation which works parallel upwards from a near contour guide-line.

As with the cultivation of the primary valley shape it is better not to continue the parallel cultivation mindlessly too far from any guide line. Two or sometimes three contours at appropriate distances apart may be used if necessary to guide the cultivation.

The combined effect of valley and ridge cultivation can be seen in the following photo.

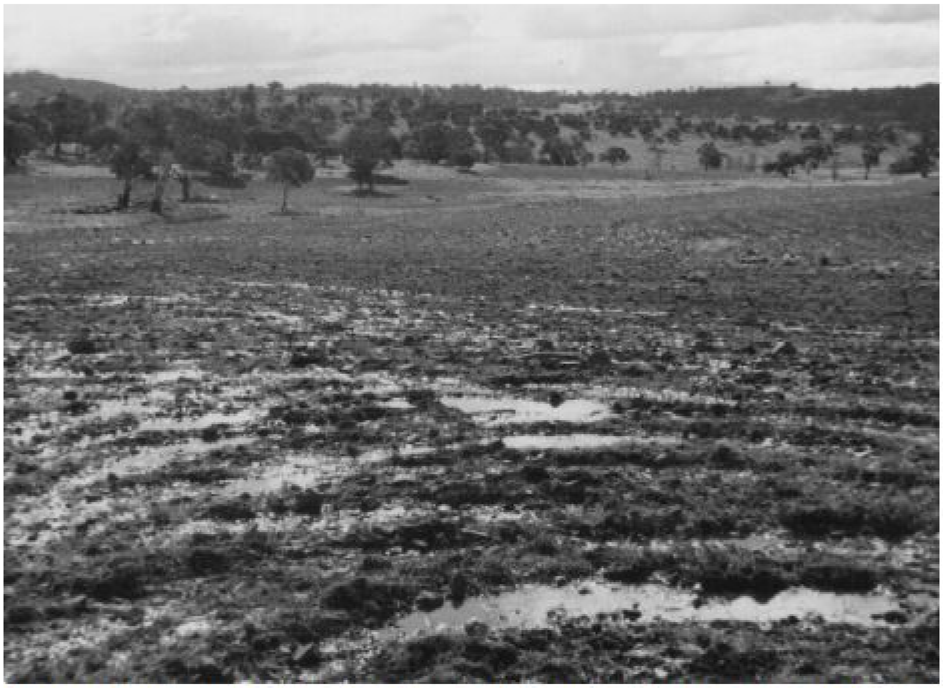


Plate 3 Keyline pattern cultivation holds water on a primary ridge. The source water can be from heavy rain or from the flooding stream from a Keyline irrigation channel. In either case the water is restrained from running off the ridge and has time to soak into the soil.

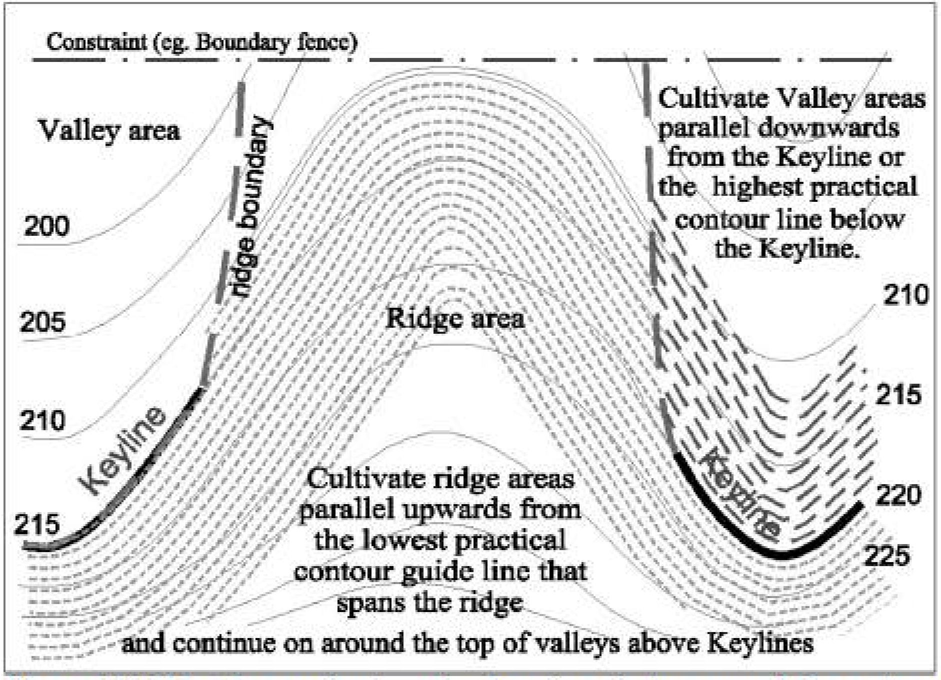


Figure 12 This plan emphasises the boundary between and the pattern formed by primary valley cultivation and ridge cultivation. After the cultivation is done the boundary becomes indistinguishable.

Plate 4 It doesn't take much to control shallow flowing water. This photo shows parallel streams of water flowing over a brick pathway. The water entered the area as a single stream but it was split up and controlled by the pattern in the brickwork. The flow is towards the camera.

C. Cultivation of a main ridge

The contour pattern of a main ridge above the primary valleys, which lie on either side of it, is essentially the same as the primary ridge shape except that it is much longer and narrower. The same parallel upwards-from-the-contour cultivation is employed for the main ridge as for the primary ridge. A main ridge is shown in Figure 13. From this diagram it can be seen that as the cultivation proceeds upwards from the contour guide lines the turn that needs to be made in the centre of the ridge becomes more acute until eventually the corner must be cut short or another guide line chosen at a higher level for the cultivation to proceed on the correct pattern.

Small areas done incorrectly will have little effect on the overall effectiveness of the cultivation if the general pattern accords to Keyline principles but if the area is to be flood irrigated more care is needed to maximize the area where the correct pattern for the desired water spreading effect is done.

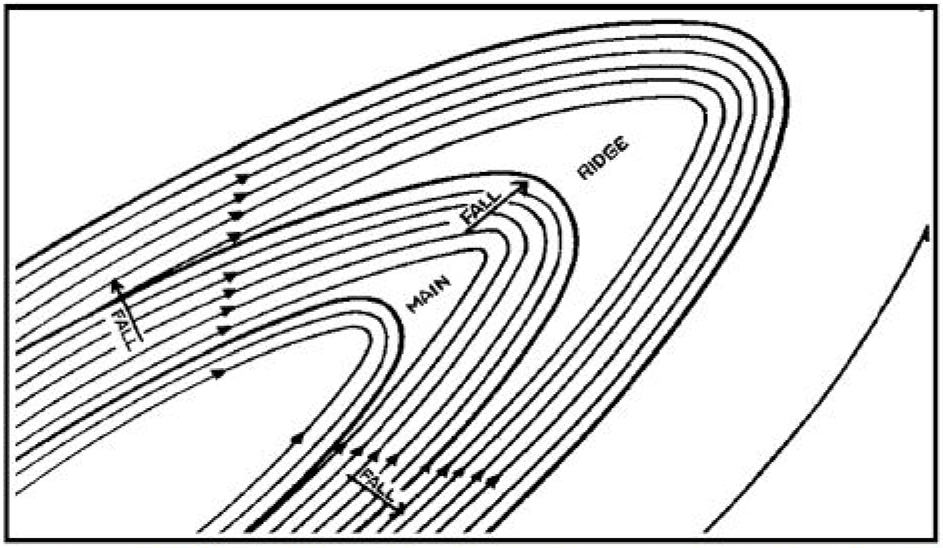


Figure 13 Showing the automatic development of a pattern that will drift the water toward the centre of the main ridge. Ridge cultivation is parallel upwards from any guide line. The small arrows show the direction water will drift across the slope in the rip marks.

1. Selective control of surface flows.

Figures 14 and 15 below are contour diagrams of the same area of land. Together they illustrate the type of selective control over the flow direction of run-off rainfall and flood irrigation water, which Keyline cultivation places in the hands of the cultivator of land. Both contour diagrams illustrate an area on which the slope near the western fence is approximately twice as steep as the slope on the eastern side. The direction of the curve in the contour lines indicate that the land is part of the side of a ridge shape. The highest area us the top left and the left side is steeper than the right side of the area,

In Figure 14, the selection of the correct contour guide-line and the parallel cultivation appropriate for spreading flowing water from the steeper western to the flatter eastern side is illustrated. The selected contour is the lowest contour that spans the full width of the area. The whole area need not be cut out from the one line. If necessary a second contour guide-line could be selected possibly half way up the land, for instance the 49 m contour of the diagram. The area below this additional contour guide line remaining un-worked when the parallel cultivation first reaches the 49 m contour on the western end, may be cultivated out by continuing upwards parallel to the work done or by any other convenient means.

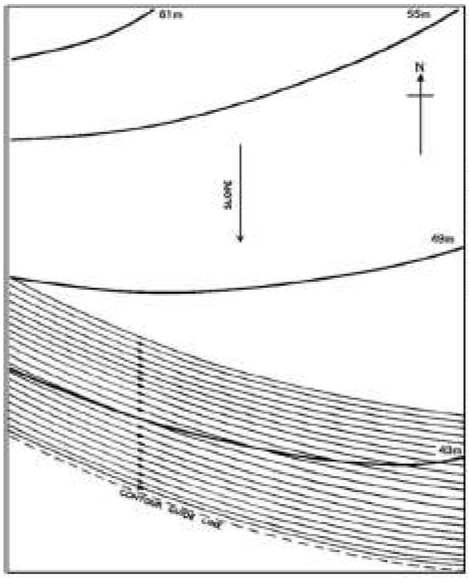


Figure 14. This diagram shows that by selecting a low guide line and working parallel upward on the ridge, the off contour pattern that develops automatically, will drift surface runoff toward the flatter eastern side of this area.

This Keyline pattern of cultivation will enable effective flood irrigation of the ridge.

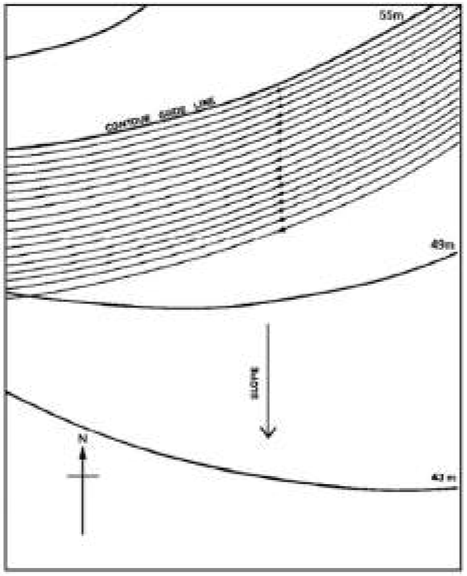


Figure 15 This diagram shows the effect over the same area when using an upper contour, as a guide line and working parallel down. The pattern that develops in the cultivation will drift water off the ridge and toward the steeper western side of the area.

This pattern will make flood irrigation of the ridge impossible.

Figure 15, on the other hand, illustrates the selection of the guide-line contour and the parallel downwards form of the cultivation, if it is desired to drift any flowing water towards the steeper land on the western side of the paddock. The contour guide line is then located from the lower of the two corners on the northern fence, and cultivation parallels this line downward. This would concentrate water on the steeper area which is not normal practice for water control on a ridge.

D. Doing the seemingly obvious doesn’t work.

Although any cultivation parallel to a contour guide line is “contour cultivation”, it is not necessarily Keyline pattern cultivation.

A Keyline pattern irrigation channel should not to be used as the guide for parallel cultivation when curving around ridge shapes. Doing so will produce a pattern that will direct the water away from the centre of the ridges shapes making them virtually impossible to flood irrigate.

This occurs because as cultivation proceeds on the lower side of the contour guide line, height is lost but not at the same rate. More height will be lost on the steeper sides of the ridge than down the flatter middle area. All too soon one will be ascending towards the middle of the ridge and after crossing the centre line of the ridge descending towards the adjacent valley. This will occur even though driving parallel with the contour channel guide line.

Cultivation done this way, i.e. parallel to and on the lower side of an irrigation channel, one will discover that the only areas where the desired water spreading effect will occur is when curving through the valley shapes below the channel.

In undulating landscapes the valley shapes are usually relatively small areas. The majority of the land below an irrigation channel is likely to be ridge shaped and these ridge shapes must be cultivated by working parallel upwards towards the irrigation channel from some suitable, lower contour or near contour guide line.

When an appropriate pattern of cultivation is developed below the first irrigation channel, the pattern will effectively irrigate the ridge shapes and spread any water flow in valleys wide and shallow. However there is likely to be a lower limit to the effectiveness of the irrigation and once discovered this will guide where to construct a second and lower irrigation channel.

VI. WATER CATEGORIES OF KEYLINE

Water provides the major part of the value of all agricultural land, and probably as high as 95 % of it in very many cases. It follows therefore, that **to allow water to run off a property needlessly, is extreme waste**.

For example in the drier western country of New South Wales, land may only have 250 to 300 mm (10 to 12 inches) of average annual rainfall as its sole water resource. This land may be worth little more than $10 to $35 per hectare ($4.00 to $14.00 an acre). The same type of land, or indeed land that is less rich in soil minerals, but enjoying an annual rainfall of 660 to 750 mm (26 to 30 inches), would be worth $250 to $750 per hectare ($100 to $300 per acre) or more, that is twenty times as much.

Water stored on a farm for later use can become, with the aid of good design, its own great work force because of its elevation and flow volume. It distributes this force in irrigating the soil and, as the water moves down through the soil, it draws air in behind it.

Insufficient water in the soil limits plant growth and too much water in the soil over long periods has a similar destructive effect. There must be movement of water through the soil so that air can return to it. This natural re-aeration is necessary to enable aerobes to continue their beneficial duties that provide nutrients to the plants.

A pasture over-wet for too long may wilt in the same way it does through lack of moisture. Its composition changes and soon it is no longer good stock feed. It may become good insect food and then pasture pests invade and breed up. If water-logging continues, the pasture grasses will die out. Water weeds which get their air through hollow stems, will replace them.

Water movement over the land may be “too slow”, this restricts the growth of valuable plants. If water moves too fast and in too concentrated a stream it becomes an earth-moving force that will eventually wash away the soil.

A. Water movements in soil

Again, there are two distinct movements or rates of movement of water into soil. When water is applied rapidly, irrigating a soil in need of water, there is firstly, a very rapid penetration of the aerated topsoil. The topsoil may only be a few centimetres (a couple of inches) deep. Immediately upon the saturation of this topsoil, there is a very sharp decline in the rate of water penetration. The penetration of water from this surface layer into the soil or subsoil below, limits the amount of water that can enter the soil. This in turn will determine when the next irrigation is required. The second rate of penetration may be more than a hundred times slower than the first. When this occurs it is better that excess water flows off the land altogether, than the soil be allowed to become over saturated. However adequate physical aeration of the topsoil and subsoil with appropriate equipment will result in an adequate supply of water being adsorbed quickly into the soil.

Properly planning the full development of land should follow an evaluation of the water resources available for the development. To assist this evaluation, Keyline planning divides farm waters into four categories and then considers the various relationships within the categories.

B. Water Categories Of Keyline

1. Absorbed rainfall.

Water of the first category that belongs to the land is the *rainfall absorbed by the soil*. It falls directly on the property. This water is of the best quality and its price is the lowest. Moreover it is the farmer’s own; no outsider can rob him of this water and no one can turn off the tap. Only the farmer himself may rob his soil and his land of this high quality and free water, by using methods of soil and pasture management that prevent its maximum absorption and beneficial use.

2. Run off.

Water of the second category relates closely to the first. It is the *run off water* from direct rainfall that has exceeded the field capacity or the soil for the time being and now flows over and off the land. In conditions of general rainfall run-off, this water moves from the ridge to the valley areas of the farm. It then flows as a stream down the floor of the valley to the creeks and is lost. This run-off water, within one’s own farm is logically the farmer’s to control. It is usually good quality and useful for all purposes. He may control, store and use it, or allow it to run to waste. Unfortunately, a design science exists that specialises in assisting flowing water to run to waste from farms. Soil conservation contour banks and grass water-ways are the hall marks of this inappropriate property design system. In many cases the banks are designed to discharge the water into the valley shapes at a higher position in the valley than the water would naturally occur and this can cause wash and erosion. Fortunately a growing number of farmers are realising that it is a great folly to have their property designed for the “safe disposal” of their run off water even when government funded.

3. External sources of surface water.

This category *originates outside the boundary* of the farm or grazing property. It flows onto the farm usually via the primary valleys and stream courses or in some cases from irrigation supply pipes and channels. It may leave the farm without even being seen. This water on the farm is not entirely the farmer’s own, since others with some right to it may be interested in using it. Before this water can be used or stored for use by the land holder, it is normally necessary to obtain a licence from a Government Authority. Apart from preserving the rights of other possible interested parties, these authorities are committed to assist in the improved use of water and are generally helpful to the farmer.

This water is usually of suitable purity for agricultural purposes, including irrigation, but it should always be checked to determine its salts content since only a small quantity may make it unsuitable for irrigation in the long term.

4. Ground water.

Ground water is the fourth category. It is water that comes from beneath the surface of the land itself. It occurs in springs, wells, subartesian or artesian bores.

All agricultural holdings possess water of significant value in some of these categories. There is no other source of supply.

* * *

These water categories require further description. Water of the first category, that is direct rainfall that penetrates into the soil, can be the only, or the principal, source of water available in some areas. There may be no run-off from rainfall, no flow-in from outside, and no ground water. On occasions the pasture improvement of some land of previous run-off record, may so increase the entry into the soil of a meagre rainfall as to prevent run-off. This may make it necessary to leave small areas undeveloped or intentionally compacted so that they will provide run-off water for filling stock dams.

Methods of soil improvement that are designed specifically to take more water into the soil, would appear to be useless in the above conditions.

However, since the general systems of grazing management tend inevitably to reduce the adequate aeration of the soil, cultivation of the right kind will improve them by improving soil aeration and result in better quality pasture and more of it, without extra water coming into the picture at all. Moreover, improved management of pasture on its own can likewise improve the soil and both the production and the quality of production, still without further water being made available. Again any result from planning or design that retards the drying action of wind is a further improvement.

However, since rainfall generally does produce run-off the first consideration in the improved use of direct rainfall may be from soil treatments that cause more of it to enter the soil. A three year course of soil and pasture improvement is a suggested program to follow. Unless deep tillage equipment is available that does not bring the subsoil to the surface and mix it with the topsoil, there is no point, and only additional expense and loss of water, in deep working the soil. This can force the soil to take in more water from direct rainfall than it can effectively make use of at its present stage of development, especially if the topsoil is being excessively diluted by mixing with subsoil. Deep soil, which is also fertile, can take in and effectively use much more water than can a shallow soil that is only in its first year of treatment.

From this discussion it is immediately apparent that low costing cultivation may give improved use in the soil of direct rainfall. Reduced rainfall run-off is likely and on occasions even drastically so because of this procedure of soil improvement. The absorbed water often resurfaces as springs of water in both new sites and old dry ones. The quality of the spring water will reflect the quality of the soil management program. If the management program is significantly increasing the humus content of the soil then the ground water is likely to be of good quality. If not salt is a real risk.

Water of the second category, namely rainfall run-off from the particular farm itself is, for the immediately foregoing reasons, seen as liable to be affected by soil treatments which may induce more water from direct rainfall to enter the soil. In some circumstances this may have an effect on the planning of farm development.

C. Water for storage and later use.

The water from rainfall run-off on the farm cannot be used at the time it first becomes available. In order to make use of it, the water would need to be diverted into one or more storages built for the purpose, and be held there for later use in irrigating the land when the soil has need of it. At this juncture it would seem that the critical planning details, locating the diversion channels and the sites for storage dams for this water needs immediate consideration. However this is not so since no artificial water lines (channels) for water control and use should be fixed until all the sources of water are fully considered.

Water of the third category flows onto the specific area from an outside source. There are two general modes of its arrival.

Firstly, the source that is likely to provide the most water is a constantly flowing or intermittently flowing stream that receives its water from a catchment situated further up and outside the farm.

Secondly, primary valleys may be partly on and partly outside the farm, and rainfall run-off from the catchment area outside flows to the farm via one or more of these divided primary valleys. In this event the keylines of these primary valleys will also be outside the farm.

Water of this third category is now seen to be affected by the farm’s rainfall run-off water of the second category, which joins with it on the farm itself. Water flowing to the farm via stream courses is normally joined by farm run-off water flowing to these streams via the primary valleys of the farm and, if not prevented from doing so, both waters will flow together from the farm and be lost.

Water of the fourth category, ground water, may be made available to the land from just below the surface or be brought up from hundreds of metres (thousands of feet) down. Ground water may generally play a less important agricultural role now in the better rainfall districts. However it is the incidence of artesian and subartesian waters, below vast areas of land with only a few inches (around 100 mm) of unreliable annual rainfall, that has permitted the carrying of great numbers of sheep and cattle in conditions that would otherwise be impossible. Useable and very valuable ground water does exist also in many areas of better rainfall where the unpredictable incidence of dry spells and of shocking losses from severe droughts, take a serious toll on constant production. It appears that, except for the fairly wide official knowledge of the artesian and sub-artesian basins, ground water generally may be an enormous untapped and undiscovered agricultural resource. Its discovery and investigation must be considered as generally outside the capacities of the lone farmer, even though ground water could exist below his own land and of a quality and quantity permitting its profitable use.

Ground water has wide variations in both quantity and quality. It may be available only as a mere trickle or up to rates of flow of 450 kilolitres or cubic metres (m^3) per hour (a hundred thousand gallons an hour) and more. It may be so salt laden as to be useless for any purpose, or vary from this condition through to a quality that is suitable for watering a vegetable garden. A lot of good quality ground water is associated with the gravel and sand beds of present day, as well as geologically ancient river systems and old lake sites. In some cases the past geological formations show that these possible sources are disguised by the present surface's solid geology.

Other than for stock watering and household uses, ground water in some cases can have substantial potential for irrigation.

Firstly, the water may be available in sufficient quantity for direct pumping from wells or bores and be applied to the land by the type of irrigation that is best suited to the land form. Secondly, the water at its available rate could be accumulated in a storage dam constructed for the purpose, where continuous day and night capacity pumping would provide the maximum quantity of water. The water stored from 10 to 12 days pumping may then be spread over an irrigation section of land at the rate of flow warranted by the land's form and shape.

These foregoing descriptions of the Keyline classification of the waters of farm and grazing land, while not appearing in this form in the earlier Keyline books ("the Keyline Plan" and "The Challenge of Landscape"), were presented by P.A. Yeomans in a paper to the Sydney conference of the Australian and New Zealand Association for the Advancement of Science in August 1962.

The assessment of the water available from categories 2 and 3, which may usually provide the principal irrigation potential, appears at first glance to present considerable difficulties. Indeed, this is so, since the class of information which may be available from Government Departmental sources has never envisaged the maximum development of this collectively vast water resource. In the eastern States of Australia, information is sometimes available from these departments as to the minimum annual run-off. This information is considered to be of value to an owner of land who may wish to construct dams of assured filling capacity for stock watering purposes and sometimes irrigation.

Stock and irrigation water involve completely different and even opposing considerations to such an extent that information of value in planning stock watering requirements may have no bearing whatever for the planning of farm irrigation developments. For instance, a first gauge to the value of stock water storages is that the water never runs short; each storage must be relied on over the extended periods of drought. If these same considerations were applied as the basis of design against each water storage of a projected farm irrigation development, either the full project would be abandoned before it started, or the planned development must envisage the waste of most of the water. A project which is designed to fully control and profitably use as much as possible of the water that becomes available, must not hinge on the criteria of annual reliability but on maximum utilisation of the rainfall opportunities.

D. The two costs of water

On our own property, complete "reliability" would have cost us greatly, by wasting at least 70% and probably 85% of all the waters from categories 2 and 3.

Every kind of water resources development has two major costs: The cost in money and the cost in water itself. This latter cost is water wastage and always reaches the greatest water waste with the highest degree of reliability. Complete reliability means that no matter what the weather conditions or how severe and long the drought, there will still be water remaining for all its designed purposes.

This type of reliability is appropriate in the storages used for the water supply of a large industrial city. It does not matter if four-fifths of the stored water is still available in the dam, and therefore wasted when rains fill and overflow the storage, as it may waste much more water in this second manner of overflow, than the full capacity of the storage. In a similar fashion, the large Government irrigation projects with their vast storages and equally costly channels for water distribution and control, are designed to have a high degree of reliability and therefore, to waste enormous quantities of water. It could be argued that this must be so since large towns, which were made possible by the availability of the water, depend absolutely on the reliability of the irrigation water and the only matter for consideration is that sufficient water is always available to fulfil its designed purposes. It is physically impossible not to wastewater.

The planned waste of water, where it is necessary to purchase “reliability” of water supply for the large city, is an essential and justifiable basis of design; and perhaps it is so also, if to a lesser extent, for the large Government irrigation area projects. Nevertheless it cannot be a sound basis of design for the development of farm water resources where these involve irrigation. This is particularly so in circumstances where, even with all available water being controlled, stored and used, the limiting factor in production would still be lack of water. Is this not so on much of the agricultural land in this country that does have undeveloped water resources?

The attitude of mind of the farmers and graziers to the water resources of their own land is of paramount importance to the nationwide development of these resources. It is time to abandon the traditional concepts on water from the older countries with climates that are less harsh than our own. There are also many academic and scientific dogmas and conceits relating to water generally that should now be abandoned in favour of more realistic and practical thinking and action on these matters.

For instance, an approach that demands complete reliability of the farm irrigation water supply, will often limit the area to six hectares (fifteen acres). This produces high cost (per unit area) irrigation, in circumstances where a like amount of money could start a much larger area of irrigation that could be progressively expanded. It may not only cost considerably less per hectare (or acre) to produce, it will also cost so much less per hectare (or acre) to run and thus be profitable for the production of a greatly increased range of products.

E. Stored water, a second savings account

In the development of his land’s own water resources, a farmer should be able to think of his stored water as a second bank account. Provided he can take the water out of the dam quickly at a low cost then spread it over his land with similar speed and low cost, he can then “trade” the necessary water for the crop he wants or the pasture he needs for his stock. Why can’t he continue to do just that and, if need be, use up all the water of the storage? True, he is then without the water as such but he has more than the value of the water in what the water has “purchased” in crops and pasture. An empty irrigation water storage dam then is not the sign of failure but quite the reverse. Rather, a full dam in a drought would be a sign of failure. If the owner could not get the water out and onto his land cheaply to save his stock because it would now be too expensive, the full dam is not a sign of “success”, but a badge of failure.

However, the position of farm developed water resources, which involve the irrigation of a substantial area of the holding, would rarely involve such a use-or-hold decision as this example would indicate. Some dams will be larger than others and one or more may have a lesser area to serve in respect to its storage capacity, while another may have very favourable replenishment features. Therefore in the protracted dry spells and real droughts the combined water storage shrinks, probably by first one dam and then another, together with their respective irrigation areas, progressively dropping out of the irrigation procedure.

When only enough water for stock purposes remains in a dam, irrigation from that dam must cease. With the dry spell persisting, the owner will always be able to predict this discontinuance of irrigation from a dam well in advance and be able to make his decisions accordingly.

There are yet other factors which may operate in dry times to assist the farmer in the management of his waters for irrigation. For instance, and as with many Keyline layouts now operating, dams for the storage of irrigation water are often inter-connected both above the dams and below them. The linking together of dams so that the overflow of one feeds around the contour to another dam in the chain. The “Lockpipe system”[1], permits the rapid release of the water for either irrigating or for the transfer of water around the property. The irrigation channels of these dams can interconnect. Thus the dwindling water of two or more dams may be reserved to the one irrigation paddock while withdrawing from irrigation the area that is normally serviced by one of them.

The same inter-connected or chain type layouts often involve dams, or even chains of dams, at two and sometimes three different levels. This permits the transfer to a lower dam of lessening water reserves to maintain full irrigation on particular paddocks. It has been found in practice that the more severe the drought, the more marked is the tendency for the dams located in the higher parts of the property, to run out of irrigation water. Also the further down the property one moves the more water is still available. One of the reasons for this is that the most favourable sites for dam construction are often associated more with the middle and lower slopes. Further, the filling characteristics of the dams generally improve toward the lower country.

If waste of water is to be absolutely prevented it would be necessary to know exactly when it would rain and it's quantity, so that irrigation could be so arranged as would cause all dams to become empty at the one time, just before the filling rains arrived.

There are indeed a few places on the earth's surface where both the rainfall incidence and the amount to be expected are so consistent that water usage from farm dams for irrigation could be precisely planned. While such weather forecasting is an unattainable Utopian dream to most landsmen, they can still do a lot better with the water from rainfall by using the logical methods of planning and design. Logical methods of using water do not involve avoiding the use of irrigation water because there might be a drought and one might run short of water. It is much better generally to "cash" his stored water at the first and every available opportunity thereafter.

F. Water use strategies

The use of available water is more efficiently done if it is properly designed. The design of water use from various farm dams must reconcile several possible rainfall patterns. Firstly, the future rainfall for the next year or two may be such that the landsman cannot use up his stored water as fast as the supply is replenished. Secondly, the future rainfall may provide one or two run-offs and then a long, dry spell. Thirdly, there may be no more run-off for a year or more.

In the first case, if irrigation water is not used on every occasion where it would be profitable, water has been wasted by not being used. In the second case run-off rainfall could be wasted if water flows off the property while some dams remain unfilled. Therefore the design of water use should provide for a quicker and larger draw from the last dam of any chain of dams. Then final run-off water would be trapped in this dam and not run to waste from its spillway if it was over-full. If such a dam becomes short of water for its own irrigation area, water remaining in the higher dams can be used to service the lower irrigation area or to replenish the dam as required. In the third case of immediate drought the above design of water use will not have wasted water and the severity of the earlier part of the drought will be postponed.

These comments on dams and irrigation have been made on the subject of the assessment of farm water resources, so that the progressive nature of the developments from Keyline water planning may be more fully understood.

VII. SMALL IS BEAUTIFULLY BETTER

A. Water resource development - State hinders private.

There must be few Australians nowadays who do not know that they live in the world's driest continent. Over the last few years this water fact of life has had very wide public mention. Quite a few people, some of them well known, have used this fact as a prelude to some rather startling statements about our "grave shortage of water". The rainfall and water run-off records of the United States, which is a country of similar size nearly 8 million square kilometres (three million square miles) may be compared to our own lesser figures. How many people realise the much more important fact that these oft-quoted figures quite clearly disclose, namely that Australians are much better off for water in Australia than Americans are in the United States? On the basis of average annual rainfall of 400 mm (16 inches) in Australia and 740 mm (29 inches) in America our population of near 20 millions would appear to be several times better off than America's 200 millions. It is very apparent that the Australians do not really live in "Dry Australia", because the vast majority of its people live in the parts of the continent with an average annual rainfall comparable to that of America. Although a large part of the rain on this continent falls in dry and very sparsely populated areas, much water is lost by evaporation without doing much good or promoting any run-off. Again, on the basis of run-off water Australia's average is reputed to be about 25 mm (1 inch) per annum against America's 225 mm (9 inches), so Australians still have a sizeable advantage on the same per person basis. The run-off from the part of Australia where over 95% of our agricultural production is carried out is considerable. It thus appears therefore that Australians are, relatively, very well off for water.

Australia and America share a common belief about two aspects of the discussion on agricultural water:

(1) A blind faith in the "Big Dam" for the supply of Government irrigation water,

(2) Common neglect of the collectively vastly larger and more valuable water resources which could be used for the same purposes of irrigation and which belongs on all their farm lands, grazing properties and forested areas.

This last great water resource is treated almost as if it didn’t exist and certainly as though it was of insignificant value.

Control and storage of water resources on the farm for irrigation should have been the starting point of irrigation development. Had this been done far more irrigation land would be available than there is now, or will be in the foreseeable future.

Had economic resources been mustered for farm water, the farmer would have seen that despite efforts much water was still getting away. If the farmer saw a need for more water, he would have discussed this with his similarly placed neighbours who were affected by the same climate pattern. They would have recognised the possibility of storing more water at a place where water could be held and released as needed to fill up depleted farm storage. To work satisfactorily, the whole development would have been based on logical geographical planning. But despite this, water would continue to move off the farms because, while water is used, it is not all used up.

The main way in which water is used up is in the cooling of plants and land surfaces by evaporation. An important duty of water is its capacity to expel air from the soil as it fills it and to draw fresh air into the soil as it seeps downward to the river. This water is not used up.

A logical development of water resources is to start from storage on the farm, move to group storage by farmers and on to larger storage for several groups. The water of progressively larger development would be used in its own geographical region with the highest water use efficiency.

This was seen during the periods of Australian drought when water from the great irrigation storages by-passed its own near areas to be carried further away with great waste from exposure. The remainder was then used much less effectively far from its regional source. All through these drought periods, water was in critical need close to its original source. These nearby farms could have effectively used one Megalitre (acre foot) with an effect equal to that of three Megalitre s (acre feet) at point of delivery hundreds of kilometres (miles) away.

Production loss in these by-passed areas, where higher value per hectare (acre) farming is the rule, could have been cut by a third because three times as much water was finding its way to the ultimate outlet.

With water losses in transport estimated as high as 40 to 60 per cent, the benefit ratio could be up to 18 to one in favour of the use of water near where it fell.

The difference between the big dam and the small farm dam is seen in construction. No big dam is built without a big outlet from the bottom. This serves to get the stored water out cheaply and keeps the enclosed water in good condition by preventing the build-up of bad water. Apart from some of the farm irrigation dams, which have been built as a result of the wide spread influence of Keyline, farm dams generally have no such big outlet from the deep water even though today this is often recommended officially. If there had been a conspiracy to make this type of storage as bad and ineffective as possible, it could not have produced a worse general result.

Normally, before building a new asset, the various processes for building it are examined with the utmost care to find the best means of producing it at the lowest cost. However when the new asset to be produced is the "irrigation hectare (acre)", this ordinary business approach is outside the bounds of public thinking, or so it would seem. But the irrigation hectare, like most other things, has a "value" and since it is a production unit, so the value of it is closely related to what it will produce. The market price of the irrigation hectare (acre) is determined accordingly. Consequently its real value is the price a farmer can afford to pay for it and make a living out of it.

At present, the farmer who irrigates from his farm storages pays for the lot. But the irrigation area farmer does not pay for the big storages and reticulation lay-outs. His payments are limited at most to charges for management of the scheme.

Any agricultural water scheme whether carried out by the farmer or the government must be based on geography so that the best use may be made of the water.

What is an hectare (acre) of irrigation land worth? Here in Australia its value varies according to where it is and for what it is used. If its use is for the general production of wheat, sheep and wool or for beef raising then the value of irrigation land would be about $1,250 per hectare ($500 per acre). However there are some newer intensive grazing systems for which irrigation pasture could be used allowing the value of the irrigation hectare could be higher. For the production of milk its value could more than double to $2,700 per hectare ($1,100 per acre). Its value could double again were it to be used for horticultural purposes. In special but very limited circumstances, it will even be worth as much as it cost the Government to produce, for as far as can be determined, the irrigation hectare produced by large Government under takings costs much more to produce than it is worth, when judged on ordinary business standards.

Government irrigation land is economical only for the production of crops with a high value per hectare (acre) return, such as those mentioned last and vegetable, orchard and vine crops. But such crops may quickly reach the stage of over-production[2] and therefore the growing of them is often controlled.

Rice growing in the Victoria-New South Wales irrigation areas, is a notable example of this type of restriction when it is applied by Government Authority. Another control is the production of certain vegetables and fruits, under contract with food processors and if a farmer produces above or outside that contract, he could be left with his crop unsold or may have to sacrifice it for far less than it cost to grow. There is generally no shortage of these kinds of home-grown agricultural products in this country.

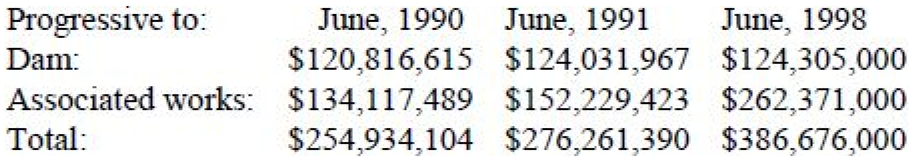
In the past it has been difficult to obtain clear-cut information on the cost of producing irrigation land by Government Authority, but when it comes to obtaining information with regard to dual or multipurpose dams where both irrigation and power generation are included, the information is even more confusing.

1. Burdekin Falls Dam - Official figures assessed.

The following section, compiled and written by the editor and merged into the text, provides some cost figures on a current “big” dam irrigation project and on farm irrigation. The following figures were updated for the 2000 edition. They provide a dramatic and relatively current confirmation of the original assessment of large scale irrigation projects by P. A. Yeomans.

The storage capacity of the Burdekin Falls dam in North Queensland is 1,860,000 Megalitres, making it the most grandiose in the state. The project is still being brought on line so it has been assessed as a current example. In answer to the question: “What is the cost to supply water to an area of irrigation?” We find in the case of the Burdekin River Irrigation project this cost appears to be about $25,805 per irrigation hectare or about $10,450 per irrigated acre. Values are in Australian currency as at 1990. This is determined by dividing our total investment by the area irrigated, and it is well worth noting, that this cost is just to supply a limited stream of water to the property, it does not include the on farm land preparation costs that are necessary for the stream of water to be applied to the soil.

The progressive (accumulating) cost of the Burdekin River Irrigation Project to June 30, 1990 as detailed in the Water Resources Commission Annual Report 1989/90 Appendices. Table AD 4 on page 10 “Expenditure on Commission Works 1989–1990” and updates released in 2000.



Progressive to:	June, 1990	June, 1991	June, 1998
Dam:	$120,816,615	$124,031,967	$124,305,000
Associated works:	$134,117,489	$152,229,423	$262,371,000
Total:	$254,934,104	$276,261,390	$386,676,000

The reports show that 16 farms were sold in 1988/89, bringing the total to 37. The total area of these 37 properties is 4,379 ha. An average size of 118.35 ha. The average of the 16 was 131.25 ha. (Source: W. R. C. Annual Report 1989/90 page 23).

The report also states “…. In addition 5,500 ha of existing development has also been supplied with water by the project.” (Source: W. R. C. Annual Report 1989/90 page 9). By summing these two we get a total of 9,879 ha.

Total investment of $254,934,104 / (4,379 + 5,500) ha = $ 25,805 per hectare.

Later in the appendices to the W.R.C. report the marginally higher figure of 11,789 ha is stated. This is made up of 8,345 ha sugar; 2,316 ha cereal and 1,128 ha horticultural crops. (Source: W.R.C. Annual Report 1989/90 Appendices. Table IAPM 10 on page 30.)

The total funds employed in the construction of the Burdekin River Irrigation Area to the year ending June 30, 1990 is $288,648,223. (Source: W.R.C. Annual Report 1989/90 Appendices. Table IAPM 17 on page 37.) These costs do not reflect the present day values as the money that has been invested in the project has been spread out over many years.

In the same report in Table IAPM 9 on page 27 we learn that a total of 250 farms are being served with the water. If we divide the money invested in the project by the number of farms served with irrigation water we discover: $288,648,223 divided amongst 250 farmers is $1,154,592 per farm.[3]

Just how big are these million plus dollar farms? To determine the average size of each farm we divide the number of farms into the total area irrigated 11,789 hectares divided by 250 farms = 47.16 hectares (116.5 acres) per farm.

The current replacement cost of the project may be close to four hundred million dollars ($400,000,000). If this figure is used in the above calculations to determine the average cost of each irrigated hectare and the cost per farm, it nearly doubles the per hectare and per farm figures.

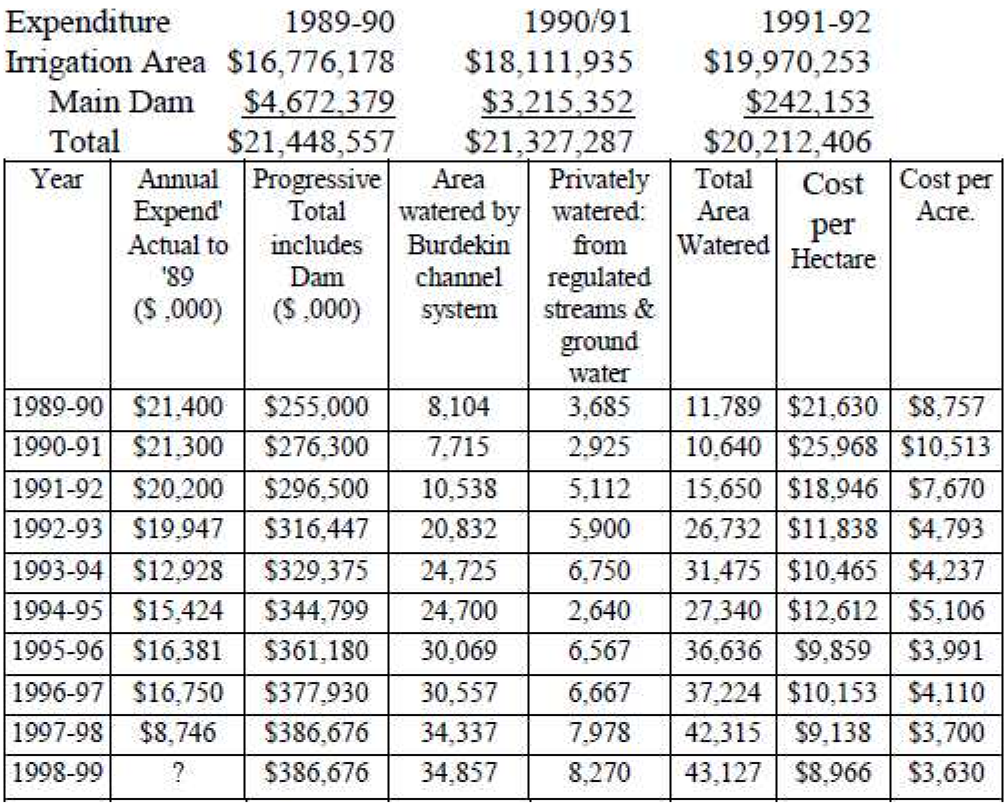
One might rightly consider that in the early stages of the project that the cost of the irrigation land may be disproportionately high. This may be the case and the following table is intended to show how the project may unfold.

The target was to bring in 500 new farms over 15 years which is an average of 33 per year. (Source: Water Resources Commission Annual Report 1989/90 page 9). That is an annual increase of 33 farms per year. Average size of farms is around 120 hectares so this is an increase of about 4,000 hectares per year. Current expenditure is around $20,000,000 per year. This calculates out at $600,000 per farm and $5,000 per hectare.

The 1991–92 Annual report stated that works were completed to enable 1,339 ha in 11 farms to be supplied with water. (1,339 / 11 farms = 122 ha per farm.) The report also stated (on page 22), that 37 new farms were available for release at the close of the year.

The table shown on this page uses these figures and project them for 15 years.

The 1990/91 Annual Report of the Water Resources Commission provides confirmation of the $20 million per year figure. (Financial Statements page 46)



Expenditure	1989-90	1990/91	1991-92
Irrigation Area	$16,776,178	$18,111,935	$19,970,253
Main Dam	$4,672,379	$3,215,352	$242,153
Total	$21,448,557	$21,327,287	$20,212,406

Year	Annual Expend' Actual to '89 ($,000)	Progressive Total includes Dam ($,000)	Area watered by Burdekin channel system	Privately watered: from regulated streams & ground water	Total Area Watered	Cost per Hectare	Cost per Acre.
1989-90	$21,400	$255,000	8,104	3,685	11,789	$21,630	$8,757
1990-91	$21,300	$276,300	7,715	2,925	10,640	$25,968	$10,513
1991-92	$20,200	$296,500	10,538	5,112	15,650	$18,946	$7,670
1992-93	$19,947	$316,447	20,832	5,900	26,732	$11,838	$4,793
1993-94	$12,928	$329,375	24,725	6,750	31,475	$10,465	$4,237
1994-95	$15,424	$344,799	24,700	2,640	27,340	$12,612	$5,106
1995-96	$16,381	$361,180	30,069	6,567	36,636	$9,859	$3,991
1996-97	$16,750	$377,930	30,557	6,667	37,224	$10,153	$4,110
1997-98	$8,746	$386,676	34,337	7,978	42,315	$9,138	$3,700
1998-99	?	$386,676	34,857	8,270	43,127	$8,966	$3,630

This table reveals that the cost to just supply water to the Burdekin irrigation area farms, may never get below $8,000.00 per hectare irrigated.

a) Water Use

Here we divide the total volume of water supplied by the total area irrigated.

1989/90 89,566 ML / 11,789 hectares = 7.6 ML per hectare.
1990/91 122,451 ML /10,640 hectares = 11.5 ML per hectare.
1991/92 211,293 ML/ 15,650 hectares = 13.5 ML per hectare.
1992/93 213,438 ML/ 26,732 hectares = 8 ML per hectare.
1993/94 230,020 ML/ 31,475 hectares = 7 ML per hectare.
1994/95 310,436 ML/ 27,340 hectares = 11 ML per hectare.
1995/96 289,577 ML/ 36,636 hectares = 8 ML per hectare.
1996/97 289,799 ML/ 37,224 hectares = 8 ML per hectare.
1997/98 260,027 ML/ 42,315 hectares = 6 ML per hectare.
1998/99 202,564 ML/ 43,127 hectares = 5 ML per hectare.

b) Water for sale - below cost.

What does the farmer actually pay for this water?

Ground water is supplied in some areas at $5.70 / ML. The price is $10.45 ($10.95[4] in 1992) per Megalitre if they undertake private drawing from the river. The price is $16 ($16.80 in 1992) per Megalitre if it is pulled from the drains and the maximum price paid by farmers drawing water from the channel is $32.75 ($34.35 in 1992 and $35.80 in 2000) per Megalitre.

In the W.R.C. Annual Report 1989/90 Appendices. Table IAPM 16 on page 36, we learn that the total revenue for the Burdekin River Irrigation Project is $3,524,808. About one third of this figure is for water sold for urban and industrial use. $2,130,472 was water charges and $129,213 was for drainage.

Farm paid revenue, consisting of Water charges levied and drainage levies thus yielded, $2,259,685.00. However in both cases the Operating Costs incurred exceeded the revenue resulting in a $382,309 operating loss for the farming section.

Thus the price paid by the farmers which may well be excessive will not even cover the administration costs of their share of the scheme, let alone interest or capital.

The entire Burdekin project was aimed at growing sugar. Following prolonged dry years at the end of the ’80s, the system was connected through to the city of Townsville, however the rains came before it was really used and the initially unplanned connection will not be needed till another series of continuously dry years, forces the city to demand the water.

Although not stated on the W.R.C. Annual Report, the farms sell *at auction* for around $200,000 each, which works out at $1,525 per hectare ($617 per acre) and this is in an *undeveloped* state.

It appears the Department is attempting another marketing strategy for the Burdekin River Irrigation Area. This was revealed in a Western Australian newspaper report dated October 1992. This report indicated five blocks of land were currently on offer, *by ballot*. The blocks range in price from $196,000 to $297,000 and in area from 100 to 120 hectares. Blocks are serviced with water, electricity, road access and cane tram routes. Water is sold to the farm and supplied by an inflow channel, a tail water drain disposes of any run off for a price, and a road to the property is built. The on farm irrigation system must be installed before the water can be used for irrigation.

The landscape of the catchment area of the Burdekin dam is also in a state of declining fertility and active decay in the form of soil erosion. The silt load coming into the dam, may well prove the demise of the project even sooner than other projects situated below healthier catchment areas in a milder climate. Perhaps the Queensland Government will stop pouring money into this project and wait till the demand for the water comes from the cities who can afford to pay for it. Certainly a better use for the funds would be to start the landscape regeneration of the vast catchment area of the Burdekin Falls Dam using Keyline techniques.

The "big" dam will invariably be the best means for providing the water for the large centres of population where the value of the water is high. But irrigation water from Government sources costs the user from about $10.00 per Megalitre to $36.00 or more, while city water pay around $1,000.00 per Megalitre. Therefore, if the expanding population of a big industrial city wants the water of an irrigation dam, who is most likely to get the water? The irrigating farmer? Not likely!

2. Farm Waters - Official figures.

In Queensland, the Water Resources Commission has a Rural Water Advisory Program which develops "on farm" water resources. It is interesting to compare the comparative efficiency.

In the W.R.C. Annual Report 1989/90 Appendices Table RWA 3 page 44 we learn that in the 1989/90 period, 18 gully dams were completed and installed by the Rural Water Advisory section in Queensland. The average cost of each project was $55,417 with an average storage cost of $222.80 per ML. The average storage ratio (water volume : earthworks volume) was 11.8 to 1. The total earthworks volume was 379,235 m^3 (cubic metres); the total storage volumes were 4,477 ML (multiply ML by 1000 to get m^3) and the total cost estimates were $997,500.

Table RWA 3 also shows 6 surface irrigation projects covering 385 ha costing $109,080 with an average cost of each project of $18,180 and an average cost per hectare of $238. Although one spray irrigation cost $4,532 per ha.

In the W. R. C. Annual Report 1991–92 in the appendices Table 3 on page 89 we find that 26 gully dams were completed at an average cost of $26,775 per project. Average cost per hectare was not attempted but the cost per ML was $334.19. The average size of these dams was 80 ML and average earthworks was 11,110 m^3 giving a storage ration of 7 to 1 (water volume to earth volume). Off stream storages were three times larger on average and stored water for around $252 per ML

Direct comparison between river projects and farm projects is a little complex. However, if we assume 7 ML of water is needed per hectare per year, then storage costs based on average dams will be $252 times 7, which is $1,764 to store the 7 ML water. Add to this an average of $238.00 per hectare for surface irrigation and we get a figure of around $2,000 per hectare for State engineers to build the dams and develop the irrigation areas. Even doubling the water allocation to 14 ML per ha still puts the cost at under $4,000 but many irrigation projects work very satisfactorily on half of this water usage.

Thus, average "on-farm" developed irrigation can produce irrigation land for $2,000 per hectare yet the large scale river dam costs from $8,000 to over $20,000 per hectare just to supply the water to the farm.

3. The storage cost of water.

The cost of water lost in water transport in large Government supply channels, has been emphasised. There is another matter of transport which accounts for a seeming paradox in cost comparison as between the "big" dam and the farm dam. Generally, in industrial processes the greater the production the less the unit cost, but not so with water and irrigation. The "big" dam, which from appearances, should provide storage for water at lesser cost per unit than the farm irrigation dam. But it rarely does so. One reason appears to be, the far higher cost per cubic metre (or yard) of earth for the wall of the "big" dam which is usually over 10 times higher than the cost for the earth placed in the farm dam. And here the cost of transporting the material is a large factor in this comparison. Whereas on the farm, a dam site to be used has to have good earth for wall construction at, and usually within, the dam site. A suitable site for a "big" dam has no such favourable feature. The materials have to be much more carefully selected and invariably carried far greater distances. Concrete walls for these structures are much more costly again.

4. The transportation cost of water.

There is another significant comparison of the two means of achieving irrigation land. In the "big" project the irrigation land is carefully selected because a free draining soil is a standard first requirement. But the problem of water loss in the distributing channels made worse by this requirement. On the farm, the land for irrigation development is precisely selected, but because of the confined area the selection is based on the position of the land in relationship to the water, enabling the cheapest application. The apparent restrictions on suitability fade with the realisation that the biological fertility and thus structure of the soil can be improved, and of course it can be improved much faster with the aid of irrigation.

The way to improve agricultural land and production most cheaply and rapidly, and very importantly, to improve the income of the farmers and graziers, is by the further economical development of present holdings and not by the too rapid bringing-in of new land. The best land is that which is now producing profitably but which, by and large, is capable of being very significantly improved.

The development of farm water resources would create a collectively vast area of irrigation land spread widely throughout all the farming and grazing districts. It would not be dangerously concentrated in the one place, or concentrated on the one class of production. It would thus create the balanced type of increase in all fields of agricultural production which would best serve the nation's progress.

5. A comparison of procedures.

Irrigation procedures for both Government irrigation district and farm developed water can now be considered and related. It will be shown that the relative size of some aspects of these two ways of handling agricultural water is not always in favour of the Government scheme.

One factor to be borne in mind is that once the water is on the farm and the actual irrigation is under way, the significance of the "size" of the Government water scheme disappears. The water may have been stored in one of the largest structures that man can make; it may have travelled many hundreds of miles in huge supply channels; been diverted by ingenious and costly control gates to several smaller and still smaller channels. But only when it arrives on the farm does the real irrigation project start. The size of this irrigation project is governed by the volume of the flow of this final stream of water, which the farmer then diverts onto his land for irrigation.

How big is this Government irrigation project now? The general answer is, that it is small. Why? Because the water is sold, for this reason it is also measured. The common measuring device is the Dethridge wheel which measures flowing water up to five cubic feet per second.

A "cusec", as this old standard of water measurement was known, is a flow of one cubic foot or 6.23 gallons of water per second, or 22,427 imperial gallons per hour which is 101,953 litres per hour.

A flow of 5 cusecs = 509,766 litres per hour = 140 l/s (litres per second)

= 0.5 ML per hour

= 12.23 Megalitres per 24 hours.

Therefore the maximum size of this irrigation stream is about 140 l/s (112,500 gallons per hour), but usually considerably less. An average flow of water is about 80,000 gallons per hour 8.69 ML/day or 363,960 litres per hour, which is then distributed by one man operating what ever features are required by the various land preparation methods.

How large a flow is 100 l/s (80,000 gallon per hour)? In an excavated irrigation channel, as used for hillside irrigation by the Keyline Pattern method, a 100 l/s flow appears and acts as a stream too small for working with, since the method and the operator could handle six times as much water and thus irrigate faster and at lower cost. A 100 l/s stream flowing in the type of channel used in flatter Government irrigation areas and with a very flat fall of, say, 1 in 2,000, it appears to be a large and impressive volume of water until it is diverted to irrigate the land when it again becomes unimpressive.

As an irrigation stream, it will water 0.57 ha (1.4 acres) in one hour, as long as it is so controlled that only 50 mm (two inches) of water soaks into the soil. These irrigation rates are far too slow and too costly in manpower.

Supposing an average flow rate of 10 ML per day is available on a continuous basis. This water should be accumulated in an on farm irrigation dam. Supposing during the peak of the irrigation season that 50 mm water needs to be supplied every ten days. In this situation a dam with a capacity of 100 ML (80 acre feet) would be large enough to store all the water supplied in the 10 days. A contour barrage dam of this capacity is described in Chapter XII called “Farm Dams - Basic Designs”. See also the accompanying figures 15 and 16. On country of 2% slope this dam will cover about 5 ha (12 acres) and hold enough for one watering of 200 ha (500 acres) with 50 mm (two inches) applied.

In many cases farm irrigation water stored in a dam, may be considered for its safety or insurance value alone. This type of approach is referred to as ’supplemental’ irrigation and it usually constitutes a stand-by reserve to ensure the production of a special crop and the possibility of a dry spell. Generally, spray irrigation now serves this lesser purpose and since the aim is to equip the area as cheaply as possible, irrigation is planned which will water the specific area in the same time as the planned irrigation cycle. An irrigation cycle, meaning the time interval before the area will need to be watered again, is usually in the range of from 1 to 2 weeks. This slow rate of irrigation greatly reduces equipment costs in a smaller pump, smaller main lines and spray lines, but irrigation is much more costly in man hours.

This type of irrigation, is not a part of the wide and proper development of water resources since it only insures against losses, but does not assure the production of extra profit. Certainly there is the exception, where such a project is for the small area production of high value crops. These projects have a place on some farms, and although the cost per irrigated area is low when compared with that of the large public scheme, they are not of the class which should in the future play other than a minor role in any major drive to develop farm water resources for widespread irrigation. Any drive in this direction would need to ensure that the larger percentage of the new irrigation land is won at low cost and that the irrigation procedures for applying the water to the land be as economic as possible in manpower costs, so that general production can be increased and not rely simply on a selected variety of high priced crops.

6. False economics of large scale projects.

It must surely be seen that any extensions of the present Government irrigation schemes, would have to be used for those items of production for which Australia has increasing overseas demand. And apart from the possible gradual rise in sales of the high value per area crops, any new large irrigation districts would need to be used for the lower value per hectare (acre) returns of general production. So any new irrigation hectares would still cost very much more than they are worth.

If the irrigation land is not worth what it costs to produce then who pays or who loses the difference between cost and value? This is a good question. The ordinary tax-payer has the rather naive notion that the farmer benefits so the farmer pays. But the answer is, that the ordinary tax-payers are the ones who pay now and who have the prospect of the continuing to pay for these undertakings into the future.

However, the development of these water resources on the basis discussed throughout this book, is on a broader scope than merely the production of irrigation land, since the objective is the planned development of all the resources of agricultural land.

Some illustrations may serve to show the sheer vastness of this greatly neglected resource.

Suppose for instance that Australian soils covering one third of the continent could have their fertility improved and their soil deepened a little, as is described further on. The soil would then be able to take in more rainfall and use it effectively. If only an additional two inches (50 mm) of rain per annum was involved, this would be equivalent to over 125,000,000 Megalitre s (100 million acre feet) of water, and be the cheapest "irrigation" of all. Further it would constitute an improvement in agriculture never before paralleled.

Does it not appear completely illogical in the first place to do anything about storing water in "big" dams for irrigation at such high cost and at the same time neglect the benefits of soil and landscape improvement with tremendously increased production, which are available so economically by simply improving on the use of rainfall where it falls.

By comparison, in the completed Snowy Scheme less than 2.5 million Megalitre s (two million acre feet) per annum will be added to the waters of the Murray and Murrumbidgee Rivers for irrigation. Australia's agricultural land of say one third of the country, would have an average annual run-off of well over 100 million acre feet (125 million Megalitre s). So there is more run-off water than in a hundred Snowy schemes. And the spear-grass and brigalow belts of Queensland's vast farm water resources, would surely supply enough run-off for many more. Practically all this water falls as rain on farm and grazing lands.

Before delving further into the cost position of the irrigation hectare (acre) from farm waters, it would be as well to look for reasons for the over-emphasis of the one and the neglect of the other.

Why should Government projects completely dominate public policy when the objective is to improve aggregate agricultural production? There are probably many reasons. Among them undoubtedly are the spectacle, the size and the glamour of these undertakings which make a powerful appeal. At this stage of our national advancement, who could argue effectively against such things with the outstanding example of the towns and the landscapes of the older irrigation areas created out of water and near desert? Added to their spectacle, are all the conveniences of city life and a bustling industrial complex starting with the factories for processing the product of the irrigation land. For centuries, a crowning achievement of civilisation has been in making the “desert bloom”. Sectional interests which could greatly benefit from such projects, are continuously demanding that “something should be done about developing the limited water resources now”. Doubtless money follows the water, why not? Of course what is meant by this demand, that something be done about the water now, is that governments have to be persuaded to do something about it. How? By arranging that all the ordinary tax-payers of the state or nation be made to pay for something which will directly benefit just a few farmers and the local business communities. Rarely, is such an undertaking sound enough from a business point of view for the farmers and business men to get together and finance it themselves, or they would do so.

If the object of an irrigation water policy is to benefit as many farmers as possible, or to increase production as much as possible with the money available, then the Government dam and irrigation project is most assuredly not the way to do it. In fact, the rapid extension of such schemes could have the opposite effect of ensuring that the vast majority of farmers cannot get any assistance with their own individual water developments. And, if a few farmers get benefits why should not all of them? Despite this, it seems that almost all farmers tend to favour and support these new schemes when they should be the chief objectors. Big dams are big business and big business always has much to say.

On another view there is a special hazard in the concentration of the highly priced agricultural products of irrigation land which is necessarily a feature of Government projects. A drop in market prices can be disastrous for the farmers and all local workers and businesses which depend on them.

Not all government irrigation and agricultural water supply schemes are as disproportionately costly. But invariable those which are considered good business propositions are the lesser projects and those are the ones which the public does not hear about. Often such fine lesser projects or starting-off schemes are good business and they would be satisfactory for private capital to support. But all too often the demand for extension or enlargement succeeds, and the reasonable relationship between costs and values disappears. Bigness itself is too often the trap. Apparently it matters not how illogical a water scheme may be, as long as it is “big” it will command wide support.

All those projects which could not be regarded as reasonable business propositions are justified in various arguments. The first being their outstanding importance in national development - and that seems to apply to every single project without exception - and the last one being that in the final analysis the profits of all who benefit are going to be taxed, so that ultimately the money spent is returned, presumably to consolidated revenue.

It is said that the necessary factor of reliability or complete safety of water supply in the government schemes, entails a tremendous cost in lost water, whereas with farm water development that factor of complete reliability can never be a reasonable basis for planning.

The totally different philosophies of the two developments become much more significant when the water run off figures are considered. The government project can be concerned only with run off water which has already reached the major streams and, except for the one high mountain development, the Snowy Mountains Scheme, the water which is to be stored has already travelled great distances. As with the great artificial supply channels, so with the natural channels of the rivers in the earth - the water travel has already cost much in water losses. As the total run off is probably somewhat less than 9 percent of the total rainfall, the loss must be considered a serious one from a national water use efficiency view. Apparently if every drop of run off were stored in big dams on the rivers, the quantity of water would still not approach that which is available on the farm and grazing land. It could be also asked; if total run off is nine percent what has happened to the remaining ninetyone percent? Water is lost all the way along the line - everywhere -and the farther it travels the more of it is lost. All the water which runs off the farm does not reach the river.

It is better to keep water on the farm, firstly in deeper living soil with greater ’field capacity’ so more water is available to the plants following rain and secondly by storing as much run off water, as is economically possible, on the farm for later reuse.

The purpose of these comments on the large “Government dam and irrigation district projects”, is to show by comparison with them the value of farm waters. If a full scale development of these waters took place for no other purpose than the production of more irrigation-lands, then they would have two great advantages over all the large scale projects of Government developments. Firstly, there is vastly more water to deal with, to produce more irrigation-land than from all other sources combined and secondly, the cost of producing this valuable irrigation land would be very much lower (and cost free to the tax-payer by comparison).

B. Limitless possibilities of farm-water irrigation.

Throughout these discussions a comparative analysis emerges on the efficacy of the two ways of developing irrigation land:

(1) By government's "big" dam and irrigation area project; and

(2) by the development of the farm water resources.

The "big" dam, the great supply channels and the tight concentration of irrigation farms in the irrigation districts are the impressive, even overawing, features. But from every possible aspect, the extension of irrigated land from farm and grazing land water resources is the best way for national benefit, and the way to improve income for farmers and graziers.

The relative size of the two, when the water actually comes into use on the farms, is very much in favour of the latter, and after all placing water into the control of the individual farmer is the object of both.

In government schemes, large flows cannot be kept available for the irrigator for when he happens to need or want to use the water. In fact, the opposite is the case; the whole working and management of the farm is usually ordered by the times when the farmer is allowed to take water. The rate of supply has to be limited, not by what the irrigator may be able to use, but by the necessity for the water authority to keep the supply channels down to a reasonable size, and to be able to service as many irrigators and possible from channels of limited capacity. Therefore the rate at which the irrigator can water his land is not governed by his capacity to do so, but by the rate of the available supply which also governs his manpower costs in irrigating.

Water from a farm irrigation dam on the other hand, is not affected by such limitations nor need it be restricted in the rate of flow of the water, by other than the practical considerations of the capacity to use the water and by the size of the dam and the related area of the irrigation paddock. If the land can be watered at a rate of flow only similar to that of the government scheme, then the greater flow can be planned for and used.

A government scheme, no matter how large could not supply each of its irrigator farmers with a flow of 1,260 l/s (one million gallons an hour). Such an idea would be considered quite ridiculous, and such a flow completely uncontrollable by any irrigation procedure. But that need not be so on a farm. That large flow for some farm developments is quite practicable, being simple to design, economical of construction and fully controllable by one man as a normal irrigation stream. It all depends on the particular circumstances, and when these suit fast and extremely economical irrigation it is better to design the working according to those favourable circumstances.

Hillsides, the irrigation of which is not a feature of government irrigation, possess especially attractive irrigation features. Hillside irrigation is not likely to be troubled by those serious problems of irrigation districts, water-logging and poor drainage. Hillside land, in the very limited field of its use, is spray irrigated at the very slow rates of from 1 to 5 ha (2 to 5 acres) per day. But “hillside irrigation” by the Keyline Pattern irrigation system is extremely practical in a very wide set of conditions and at watering rates near 4 ha (10 acres) per hour and with only one man control. Also, one former difficulty of hillside irrigation, the danger of soil erosion is not, with this system a factor for more than passing consideration.

The water available for irrigation developments, which is associated with hillside land, constitutes an enormous, untapped resource spread widely throughout the farm and grazing lands.

Every method of applying water to land which is in wide use in irrigation districts can be used with at least equal advantage on farms and from their own water resources. But further than that, because the flows rates of water on those ordinary farms are not so restricted, they allow every one of these methods to be greatly improved upon. This is particularly the case with lower costs of labour when more area can be covered each day with one man.

Not all farms have water resources which can be developed for irrigation, some, with sufficient water, may not be able to use it because the topography of the land precludes it, or because the available soils are not suitable for dam building. Problems of materials will gradually be resolved, and particularly so when it becomes the serious business of some government departments to conduct tests and to make experiments on average farms, with sufficient money to support the project aimed to solve the problems.

There appears to be no basis to the often repeated statement, that Australia is seriously backward in the development of her water resources, meaning of course the “big” dam type. In fact we seem to be as well advanced in water development of that kind as any other progressive country, particularly on a population basis. So much so that in future, that type of project should be examined more critically than in the past.

It should be acknowledged that in many cases, both with the “big” dam project and with on-the-farm waters as well that it can be good business to do nothing about the water but just let it go. There is always, what we call “waste of water” so why not “waste” the kind which would be the most expensive to hold?

It is now time for governments to encourage, by some special measures the development of the on the farm water resources. It would be good business for governments if they could promote the development of a very large total area of irrigation land at, say, one tenth of the price per hectare that it had been previously paying for it. But even that low cost would be far beyond what any reasonable assistance scheme could involve financially. In the greater proportion of cases, a practical lead and some loan finance would be sufficient inducement to persuade farmers to think again about these matters. But if it is necessary or advisable to offer bounties of various kinds, or tax concessions on the production increase which results from new irrigation lands as is done to the export of the products of secondary industry, then that would still be a means of creating new irrigation land at a cost much lower than that by any other possible means.

VIII. DEVELOPMENT OF WATER RESOURCES

A. Sources

Some sources of very valuable water supply on farm and grazing lands may be very obvious while others may not be so, and can even be completely concealed and unsuspected. The sources of supply for Flood-flow irrigation are similar, generally, to those which may be available for other systems of irrigation except that because of the necessary flat land associations, storage dams are generally much larger and tend also to be shallower.

1. Run-Off Rainfall

There are dam storages which may be filled by run-off rainfall. A storage dam, or dams of suitable capacity may be constructed and filled with rainfall run-off water from the dam's own natural catchment, or run-off from a sufficient outside catchment area may be diverted to fill the storage. A lock-pipe system of suitable size is envisaged which will eventually release the water from beneath the earth wall of the dam as is required for irrigation.

The size of the dam is in accord with the local circumstances of rainfall run-off, land shape, and the related capacity of the storage and to the area of land which may be available below or near the supply for irrigation. The widely varying circumstances on individual properties will produce an almost infinite variation in the shape, type and capacity of these storages and thus affect their rational uses.

Farm storages will probably provide more water for the greatest irrigation potential and could lead eventually to the development of more irrigated land than all other public and private water sources combined.

Another type of outlet for irrigation water, additional to a pipe beneath the wall, may be utilised if such a dam is constructed to tap a perennial stream or which for some other reason can be kept constantly filled. In these circumstances, a water-gate may be installed in a position to control and release water to flow from the uppermost half metre (twenty inches) or so of the dam.

A storage that can be kept constantly filled could have two types of outlet:

(1) A lock-pipe system through the bottom of the wall, which could supply water to an irrigation channel positioned at this lower level, and

(2) one or more water-gates to supply water from the top of the dam to an irrigation channel on this higher level.

Again, when the stream flow is less than usual, the land serviced by the lower irrigation channel can be maintained in a fully irrigated condition, whilst the land serviced by the higher irrigation channel, receives irrigation only when the dam is filled to a sufficient capacity to supply water through the higher placed water-gates. It is a simple matter to release water from near the top level of a dam via watergates at a low cost and in a practical manner.

In other conditions a high capacity, low head pump can be used.

2. A Perennial Stream

A perennial stream of sufficient flow capacity may supply, by diversion or pumping, a minimum flow of say 2.5 Megalitre s (550,000 gallons) per hour. Such a direct source is sufficient to supply a maximum irrigation area of up to 360 hectares (900 acres) on a basis of continuous irrigation for eight hours each day on a minimum irrigation cycle of ten days and assuming that 55 mm (2.2 inches) is applied at each irrigation.

However, if this source of supply can be delivered to a constructed water storage and it is noted that very large farm and grazing land water storages are most practical on some of the flatter areas. It can then receive continuously the full flow of this stream, day and night up to the amount that can be pumped or diverted over a full irrigation cycle. If the dry season irrigation cycle is ten days then water can be accumulated for this time. The hourly flow multiplied by 10 days of 24 hours, would provide 600 Megalitre s (132 million gallons) to a large water storage. This is sufficient stored water to fully irrigate (once) approximately 1,100 hectares (2,640 acres). This assumes that 55 mm (2.2 inches) is applied at each irrigation, which is equivalent to 0.55 Megalitres per hectare (50,000 gallons per acre).

A 600 Megalitre s (132 million gallons) capacity dam on a medium sized grazing property, can be well within the financial resources of the owner. Assuming a 10 to 1 storage ratio between water stored and earth moved, the earth works would be 60,000 cubic metres, which may cost around $1.35 per cubic metre ($1.00 per cubic yard).

A potential of this size can be discovered and determined quite quickly. It can then be decided to use a flow rate of 10 Megalitre s (2.2 million gallons) per hour to irrigate at the rate of 18 ha (44 acres) per hour, whereupon 60 hours of irrigation would complete 1,100 hectares (2,640 acres). This is by no means the maximum rate of flow that could be designed.

The size of the lock-pipe system to release the irrigation water from below the wall of the dam and, or, the capacity of the water gates to release the topmost foot or so of water, is then decided by the requirements of the designed flow rate.

It can be seen that these same considerations also apply if the flow available is only one tenth of a Megalitre per hour or 28 l/sec., (22,000 gallons an hour); but then on the same basis, the maximum irrigation area which could be supplied is about 50 hectares (120 acres). In such circumstances the capacity of lock-pipes or watergates of a storage to control this flow can be designed to release the water which was accumulated from 240 hours of flow and complete the irrigation in one day. Such a storage has the very modest capacity of 27 Megalitre s (six million gallons).

Plate 5 Construction sequence of an on farm irrigation dam near Armidale NSW. The Lockpipe enables direct gravity irrigation and feeds a pump to an upper irrigation dam in the trees at top left.

(Google earth to 30°35’46.54”S 152°10’26.73”E)

Why in such circumstances should an irrigation system be installed at very much higher cost? Such a system is only designed to use the water at its available rate of 400 l/sec., (25,000 gallons an hour) and therefore can complete only 20 ha (50 acres) in 100 hours of irrigating, which is 10 hours per day for 10 days.

The present widespread practice of designing small farm spray irrigation layouts is on the basis that the time taken in spray irrigating, should extend over the full irrigation cycle. This is done to reduce the capital costs of the installation. On the other hand, on a small or one-man farm, the irrigator should not be on call every day for ten days to irrigate a small area when the minimum and critical irrigation cycle is ten days long.

To get the best management and most rewarding results from small area irrigation, whether it be spray or one of the many systems of flood and flow irrigation, the complete irrigation process should be finished in no more than half the time of the minimum irrigation cycle. If at all practicable the layout and design should provide that the irrigation be finished in one day. The most beneficial result of irrigation can be obtained by the application of water in critically dry times before it becomes stressful for the plants on the irrigated land.

A small area irrigator should be in a position to easily complete his irrigation on the day he decides to irrigate. When this is the case he is at liberty to manage other aspects of the land, namely, the soil, grass, stock, fences and crops. He should not be a man who is continuously occupied in applying water to land.

If the critical irrigation cycle is ten days but the time it takes to irrigate it is also ten days, what happens when it rains and completes the proper wetting of the whole area in a few hours or a day or so? Does irrigation commence again the day following the rain, or the next or some days later? If irrigation does not start the day immediately following rain then the paddock or portion of the area to be completed on the tenth and last day will be without water for some days at a potentially critical time for the plants.

3. Underground Water

The third source of water supply is underground which, by means of bores, is brought to the surface and accumulated in a storage. Such storages will generally be of the flat land type. For example: a large valley storage; a contour dam which is very suitable on slopes of 1 in 50 to 1 in 100; or a large ring dam which is suitable on the still flatter lands.

Again these sources of supply can use a lock-pipe system of calculated capacity which may release the water into an irrigation channel. On some occasions water-gates are suitable for releasing the top half metre or so (one to two feet) of a filled storage’s water.

B. Limitless Scope For Farm Irrigation.

Obviously the one place where the highest efficiency in water use can be achieved, is on the land where it falls as rain. Therefore, water for agricultural purposes should first be used on the land where it falls or as close to it as is possible.

When water use efficiency is discussed, it should be clearly realised that the matter of efficiency in water use is purely relative. Likewise so is waste of water. It has nothing in common with the efficiency qualities of industrial processes or of “cutting the coat to suit the cloth”. Water is a moving process and it continuously moves on. This fact can account for the seeming paradox which emerges on many occasions. It often happens that the more water is used the more water is available to be used and the sure way to really wastewater is not to use it. Country people may sometimes be concerned about the extravagant water habits of city dwellers. But what does it amount to? No matter how frugal their usage of water, may be none of it would be available to the country and for agriculture. So long as city water does not run short to the stage of water restrictions, then it is better that the water be kept moving. It is quite impossible to know when water is actually being wasted, without at the same time, knowing when it is next going to rain and how much will fall. There will always be, what is called, “waste of water”, so why not waste to the ocean the kind that would be the most expensive to hold.

The cost of farm developed irrigation areas, produced as part of the Keyline development of land is met now by the owner of the land, and this first fact should ensure that it is not going to cost more than it is worth. Because of the nature of these water developments and their position, as part of a general planned improvement programme, the production of more irrigation land will be in step with other parts of the improvement programme. Moreover, because of the progressive nature of the farm water developments themselves, the farmer is able to continue a program, change it, abandon part or all of it, according to results.

The cost of economically producing the irrigation area from farm water resources which have to be completely developed, may range from $250 per hectare ($100 per acre) upwards.

1. Irrigation - An Overview.

The land of our former properties, “Nevallan” and “Yobarnie” at North Richmond, New South Wales, is of a medium undulating character, where the slopes range from 1 in 3 to 1 in 26. It was from this topographical background, plus that of the low fertility clay soils and the completely unreliable incidence of the 660 mm (26 inch) average annual rainfall, that the principles of Keyline were developed from work begun in 1943.

While there was no flat land on “Nevallan” and “Yobarnie”, we were aware, and it was soon proved, that the general techniques of Keyline would be applicable to the much flatter areas. However where, on these flatter lands, Keyline planning involves water control for low cost irrigation, then considerable alterations in the planning detail and construction procedure is necessary.

These new methods of water control were worked out and first tried at “Yobarnie” and it was soon discovered that low cost flood irrigation was practicable on our most gentle slopes.

In the irrigation of undulating land by the Keyline Pattern irrigation system, an irrigation rate from each channel of 1.5 - 3.5 hectares (4 - 8 acres) per hour per man, is a simple matter and has been for many years. But there are certain factors of farm channel construction and water control which impose limits. Faster rates than 4 ha (ten acres) per hour with Keyline Pattern irrigation on undulating country are not as yet, considered widely practical unless multiple channels are used, in which case the rate of irrigation increases proportionately.

On land flatter than 1 in 30 the same limiting factors do not apply, consequently the rate of irrigation is only limited by the available water and the shape and slopes of the land.

In Keyline Flood-flow irrigation, apart from the matters of the water supply, the land preparation construction costs per irrigated hectare (or acre), do not increase with the greater rate of irrigation and indeed may be reduced. For instance, if a projected irrigation stream of two and a quarter Megalitre s (half a million gallons) per hour could be increased two, three, or four fold, land preparation costs per hectare (or acre) are proportionately reduced. In the first place one man would be irrigating at a rate of about 4 hectares (10 acres) per hour. With the increased flow he could irrigate two, three, or four times as much land per hour almost as easily. In addition, the methods of water control and soil management within the Keyline plan, enable the irrigator to also exercise control the soil’s water intake, which is at least equal to, and generally better than, that obtainable in a more orthodox system, which may be only irrigating at one or two hectares (two to four acres) per day.

2. Keyline Irrigation for flat or undulating land.

The Keyline approach to flood irrigation may be better understood by appreciating that in undulating country a large stream of water will tend to concentrate. Because of this, the irrigation system must be designed to cause the water to spread. Keyline Pattern irrigation achieves two ways.

Firstly by enabling the water to gently spill, as a wide shallow stream, over any chosen section of the irrigation channel and secondly by utilising the unique Keyline pattern of cultivation rip marks on the land below the channel. The pattern of cultivation spreads and the water wide in valley shapes and restrains it from drifting off the sides of ridge shapes.

In flatter land the approach is reversed because uncontrolled the stream of water will spread out slow down and over water the area near the channel. It is important to appreciate and understand that on land of gentle slope, even a very large stream of water will spread widely and dissipate its power-of-movement which it derives from the large volume of flow and the head (or elevation) of the water in the irrigation channel. In Keyline Flood-flow irrigation it is the steering banks that hold the stream within a confined course, thus preserving its positive forward movement. The pattern generated by cultivating the land is employed for the more intimate spreading of the irrigation water within irrigation bays, which are formed by water "steering banks". The direction of the cultivation may even be parallel with the steering banks, though in general the pattern of cultivation should be standard Keyline pattern cultivation. The cultivation can be used to spread the water and the steering banks prevent the sheet of water from spreading too wide.

There is a great work force residing in, or resulting from, the mass of a large flow of water. The Keyline Flood-flow irrigation system is designed to utilise this work force with the maximum efficiency, both in spreading the water effectively over the land and in the crucial intake of that water into the soil itself.

Keyline Flood-flow irrigation like the earlier Keyline Pattern irrigation and the other Keyline technique, are designed primarily to be a part of a complete Keyline plan for the property on which it is to be applied.

A Keyline plan is always unique to each particular farm or grazing property; the shapes of the land in relationship to the water resources available for development is the deciding factor in the plan layout and the methods of applying irrigation water to the land.

Privately owned on-the-farm water resources may be developed to provide water for various systems of irrigation; thus any of the several methods of spray, flow or flood irrigation may be employed according to the particular circumstances existing on the different properties.

Whilst farm waters have been neglected as we have said, there has been, on the other hand, a notable but relatively small part of this great potential only recently used in the construction of farm dams for the purpose of supplying water for irrigation.

Spray type irrigation has so dominated the thinking in this development, that any mention now of “irrigation” from on-the-farm waters is often taken to mean spray irrigation only. There has thus resulted a complete neglect, even an unawareness, of every other method of applying water to the land. Furrow irrigation has expanded much, however the actual inundation times tend to be far in excess of what is optimum for healthy living soil.

In considering the various methods of irrigation, it should be kept in mind that there is not always a clearly discernible area of distinction here. The one system ceases to be applicable and another system replaces it. On some occasions, the unique techniques of the one may overlap those of the other. This could be so where the choice may happen to be between Keyline Pattern irrigation and the relatively newer Flood-flow system. Since a principal aim in irrigation should always be the application of the water to the land at the lowest possible cost and, since low manpower cost can best be achieved by increasing the area of land which one man is able to control and effectively irrigate in a day, the choice between Keyline Pattern and Flood-flow irrigation systems will generally be in favour of Flood-flow wherever it can be used. There are several reasons for this preference. Firstly, because it permits the control of a greater flow of water. Secondly, another advantage of Flood-flow Irrigation over Pattern Irrigation is in the gradient of the irrigation channel, because the loss of height associated with the sloping channel of a Pattern Irrigation channel can exclude critical areas from the potential irrigation area. Nevertheless, it is possible to use a banked channel at a very shallow grade to maintain the height of the water, then release the water through only a few water gates into the somewhat steeper excavated channels of Keyline Pattern Irrigation.

The farmer or grazier should make it his business to know something of the intimate techniques of all systems of irrigation so that he may select the one which he will use in the development of the water resources of his own land. Whether irrigation will produce much profit or result in substantial losses will often depend, in the first instance, on this choice of one or other of these irrigation procedures.

Although the emphasis in this book is on farm irrigation, we are totally opposed to the general view of farm irrigation as a thing apart, having little to do with the general development of farm and grazing land. It should become abundantly clear before the conclusion of this book, that the planning for the development of all land must be based on the various “water lines” of the land itself. This is so even when the farm water resources are unsuitable for any irrigation developments.

The planning for the development of all land must have as its main objective, the maximum profitable usage of every natural and renewable resource of the land itself so that where water resources exist, their possible use in irrigation is automatically a part of wholefarm planning.

The principal plea of this book is, not that farmers and graziers should use the Keyline Flood-flow irrigation system for applying their irrigation water to their land, but that they should study and fully understand their land and its water resources, developing them where this is appropriate and show promise of good profits. They should apply these waters to their land by the method of irrigation which is most suitable for their particular circumstances. Keyline Flood-flow irrigation should then be the system chosen only where it can satisfy the requirements of being the best, the lowest in cost and the highest profit producing system.

Consider the enormous mass of water used in irrigation. In the application of 50 mm (2 inches) of water to two hectares (5 acres) one thousand tonnes of water is required. This may need to be repeated in 10 days. Precisely ordered lines are necessary for its effective control and use. These water lines must logically form the basic framework for the whole edifice of land planning.

It is important that the water lines used in landscape planning must not be those generated from the limited and wasteful procedures aimed at the safe disposal of farm waters.

a) Keyline Pattern Irrigation.

Keyline Pattern irrigation is for undulating lands with slopes of from 1 in 4 down to 1 in 30 and sometimes flatter.

For many years the recommendation was for a 300 mm (12 inch) diameter Lockpipe System under the wall of dams used for Keyline pattern irrigation. In dams over 5 metres deep this is satisfactory. However, in dams storing only 3 metres of water above the pipe, the flow rate decreases well below the optimum as the water level in the dam drops. It is preferable to be able to turn the tap on further and so maintain the flow as irrigation proceeds, than to start with a full channel of water and have the flow rate diminish during irrigation. Consequently for Keyline Pattern irrigation in undulating land a 400 mm (16 inch) diameter Lockpipe system is appropriate in dams that store about 3 metres of water over the pipe.

Plate 6 It is the Keyline 'Pattern (of) Cultivation' that spreads the irrigation water after it is spilled from the channel. The pattern of cultivation redirects and spreads the flow, which would otherwise become a more or less concentrated stream flowing down the steepest path of the land into the valley below. Without Keyline pattern cultivation this irrigation would be just "wild flood" irrigation.

The water flows from an outlet pipe in the dam directly into an irrigation channel which is wholly within the ground like a shallow trench.

The maximum size of the channel is about 1,200 mm (4 feet) wide, 600 mm (2 feet) deep with a desired maximum base width of 600 mm (2 feet). The gradient is usually 1 in 300.

Plate 7 Early photo of irrigation flags in place awaiting the arrival of the water. 100mm (4") pipe us now used to span the channel.

The operator is usually equipped with a long handled shovel and uses three irrigation flags for each channel. A flag is made of a large piece of water resistant cloth, which may be up to 3 metres (10 feet) square. It includes a similar length of a light weight pipe-bar, usually 100 mm (4 inches) in diameter, to span the channel. This pipe is slipped through a hem on one side of the flag. Through a hem on the opposite side of the flag is positioned a slightly longer length of 6 mm chain with tent peg spikes at each end of it. The chain weighs the cloth down into the channel to catch the flow of water and the spikes are pushed or driven into the ground if necessary to hold the flag in position in the channel. The pipe bridges the channel and holds the down stream edge of the flag up to block the flow. The weight of water on the flag effects an adequate seal.

Irrigation proceeds in this manner -- the area of course having been pattern cultivated within the previous 3 or 4 years. One flag is placed in the channel near the dam and a second, 18 to 24 metres (60 to 90 feet) further along the channel. The water is turned on full bore to the full capacity of the channel, to be blocked by the flag and spill down over the land.

Plate 8 Early photo of Keyline hillside pattern irrigation on Yobarnie. "Big John" Stephens tends the irrigation flag.

The operator follows a set procedure, releasing the water by moving the flags leapfrog fashion along the channel to water the land uniformly and quickly.

One simple method of removing a flag is, after first pulling out the steel spikes, to take hold of the upstream, top side corner chain and step across the channel to the lower side with the chain and corner in tow. Pull on this corner toward the opposite diagonal, (i.e. the down stream corner at the pipe). The water will start to move under the top side of the flag and as it does so it displaces the water in the flag which flows over the lower lip of the channel. Eventually the water will push past the flag and quite often the up hill end of the pipe will slide down stream as the pipe pivots on the down hill end of the pipe. On other occasions a flag can often be allowed to turn itself inside out as the water pushes the sheet under the pipe.

Stopping a flowing channel with an irrigation flag is simple and is done on occasions if it is necessary to back track a little with the watering. Stopping a flowing channel is done by placing the pipe across the channel, taking care to keep the cloth above the stream of water. Straddle the stream of water whilst opening out the flag on the up stream side of the pipe. Take care to keep the centre of the chained leading edge of the flag clear of the flowing water. Lower the chained corners of the flag into position on the upper and lower bank of the channel and step onto the flag to prevent it moving. At this stage the operator should be straddling the water, facing down stream, holding the middle of the chained side of the flag clear of the water and be standing on the chained sections of the flag on both the upper and lower side of the channel. Next the centre of the chained edge of the flag is then plunged down to the bed of the channel. It is a good idea to use a shovel or stick to push the chained edge of the flag to the bottom of the channel. The water will flow onto the flag and quickly press the flag to the base of the channel and prevent it from moving. The operator can then step clear of the flag. If it is considered necessary the spikes can be hammered into position to further stabilise the flag in this new position.

Various layout designs to suit all circumstances make pattern irrigation a one to three channel system, operated by one or two people to vary the rates of water application from 2 to 12 hectares (five to thirty acres) per hour.

In practice the initial cultivation pattern can usually be improved by the irrigator noting any difficult areas and adjusting the cultivation pattern accordingly.

When used in orchards or city forests the tree planting should be done after the best cultivation pattern for the particular area has been established, This way the planting locks the correct cultivation pattern into position and simplifies future cultivation.

b) Keyline “Flood-flow” Irrigation.

The Keyline Flood-flow system is the logical application to the flatter lands, of the same principles and some of the techniques of the Keyline Pattern irrigation system which is now in wide use for irrigating undulating lands.

Keyline “Flood-flow” irrigation of flat or nearly flat country embraces firstly, the accumulation and mobilisation of relatively large quantities of farm water from rainfall run-off, stream flow or from underground and secondly, the design and control of these waters in large flow volumes for the purpose of irrigating flatter lands.

The Keyline planning provides the design, on properties where suitable water exists or where a water resource can be developed, for the mobilisation or accumulation of large quantities of water, and for the control and release of the water onto land at a flow rate of “flood” proportions.

The result of this planned water control is that one man can irrigate at a rate upwards of eight hectares (twenty acres) per hour for the production of crops, pasture for sheep and cattle, or for dairy production.

Plate 9 First flow from an irrigation dam. 600 mm (2 feet) diameter pipe with a slightly undersize valve. Maximum flow is about 3.5 m3/sec., which is 12.6 ML/hour and 10 acre feet per hour. Irrigation application rate is up to 20 ha (50 acres) per hour.

Plate 10 Water from the valve shown in Plate 9, flows along the main Flood-flow channel towards the irrigation area.

Plate 11 The pond area of the dam, as seen from the wall, that supplies the water for the upper images. The trees around the water line shield the pond.

In the Keyline Flood-flow Irrigation System for flat lands, water for irrigation is released, diverted or pumped from the source of supply into the start of an irrigation channel which lies across the fall of the land. This channel may be designed to have a fall from the source of supply, or to be "dead flat" on a true contour in accordance with the circumstances on each individual property. This guided and controlled large stream of water is next released from the irrigation channel through water gates into wide irrigation bays. These irrigation bays are formed by earth banks, extending from the irrigation channel down the maximum, albeit gentle, slope of the land.

The irrigation of each bay is usually accomplished with all the water gates to other bays closed, there by releasing the full flow of water from the irrigation channel in turn into each individual bay. Naturally, if the flow into the irrigation channel exceeds the discharge capacity of the water gates of one bay alone then additional gates would be opened. Finally the water gates to the last bay are left open after the supply is closed off so as to use then drain the water from the full length of the irrigation channel. The following day, all water-gates are again opened to ensure good drainage. The open water gates will ensure an even distribution of water from rain fall run-off, even if heavy rain occurs between irrigation cycles.

From this description the Keyline Flood-flow irrigation system could be likened to the more orthodox border check method, which is used widely in Government controlled irrigation districts. However, the essential differences between Keyline and Government controlled systems are very great. Firstly, the available flow of water for Floodflow is not limited by the need for measuring or by other restrictions on the flow rate, as is the water for irrigating in the public scheme. In 1991, the largest measuring wheel installed on the government projects in Queensland had a capacity of 20 ML/d (Megalitre s per day) which is 230 l/s (180,000 imp. gallons per hour). As a normal irrigation will require a little over half a Megalitre per hectare, the maximum irrigation rate per wheel is 1.5 hectares (3.7 acres) per hour.

The preferred Keyline Flood-flow water stream is more than 10 times greater than in the public scheme and as a consequence of this nearly unlimited flow rate, the irrigation bays or water-runs may be 10 to 20 times larger. With such large bays, land preparation is totally different. Instead of relying on extensive and expensive levelling and grading work to ensure the even spread of a small stream of water, as is the case with border check irrigation, the large Flood-flow streams plus Keyline pattern cultivation accomplishes this at approximately one-tenth of the cost.

In Flood-flow irrigation, apart from the matters of the water supply, the land preparation construction costs per irrigated hectare (or acre), do not increase with the greater rate of irrigation and indeed may be reduced. For instance, if a projected irrigation stream of 625 l/s (being 2.25 ML/hr. 500,000 gallons per hour) could be increased two, three, or four fold, land preparation costs per hectare (or acre) are proportionately reduced. In the first place one man would be irrigating at a rate of about 4 hectares (10 acres) per hour. With the increased flow he could irrigate two, three, or four times as much land per hour almost as easily.

In addition, while this is being done, the methods of water control and soil management within the Keyline plan, also enable the irrigator to exercise control of the soils water intake, which is at least equal to, and generally better than, that obtainable in a more orthodox system irrigating only one or two hectares (two to four acres) per day.

Keyline Flood-flow irrigation is a fully controlled system of irrigation for using water resources on farm and grazing lands or forest areas in flatter country.

In order to make this descriptive exposition of Keyline Flood-flow irrigation fully intelligible, an explanation of the principles, approach and techniques of the system is provided in later chapters of this book.

3. Other Irrigation Methods

a) Border check irrigation

Border check irrigation, also referred to as “border bay” and “border strip” is used widely in Government irrigation districts. Water is released from an irrigation channel constructed generally across the fall of the land, into bays formed by small earth banks, or borders, which extend from the channel at right angles and down the fall of the land. The object is to advance a sheet-like stream of water down the strip of land between the low banks and cause the required amount of water to soak into the soil.

The borders are generally about 10 metres (33 feet) apart and the bays formed by them may be up to 140 m (seven chains) long. Border check irrigation is used for gently sloping land and up to 1 in 30 or 3%, it could be used for pasture on slopes somewhat steeper on stable soils and on up to five or six percent slopes by reducing the bay width to 16 feet (4.8 metres).

Considerable land preparation is necessary involving instrument levelling and pegging-out to mark the area for cuts and fills, several cultivations to loosen up the soil and supervision of the earthmoving to smooth and level off the whole area. The small banks are formed in two operations: Firstly a small grader with straight blade, traverses the whole field working parallel to the irrigation channel. At the crossing point in turn of each bank line, which has been clearly pegged, the blade is raised to release its load of earth. At the completion of this operation the earth for all the banks is in place forming uneven lines of banks. Then a “crowder” traverses each of the banks lines, crowding them into neat even banks about 10 inches (250 mm) high.

The irrigation channel, usually called a ditch, may be equipped with small permanent water gates through which the water is released into the bays, or the bank of the ditch may be opened with a shovel and closed up again with earth, when irrigation of the bay is completed. Several bays may be receiving irrigation water at the one time. The irrigation ditch receives its water from the “head ditch” which is the main channel on the farm and where the water is measured.

Land preparation costs may average $200 per acre but can on occasions be either considerably higher or lower. Border check irrigation is used for the growing of a wide variety of crops, including orchards, but it is especially suited for small grain crops and pasture production.

If a much greater flow of water can be made available by the construction of a on-farm holding dam then, border check irrigation could be abandoned in favour of one of two much faster and cheaper Keyline methods. Which method depends on the slope characteristics of the land and the water resources available. For example:

1. If the land to be irrigated is flatter than 3% (1 in 33) and of suitable shape then Keyline Flood-flow could replace the border check method and would be suitable for growing the same range of crops. A Keyline Flood-flow design would initially anticipate a water flow rate of 9 ML (2,000,000 gallons) per hour. Such a flow can complete 320 acres (130 ha) of irrigation in an eight hour day.

2. If the range of slope is from 3% to 8% or steeper, the border check method can be dropped in favour of Keyline Pattern Irrigation. The designed rate of flow is much less, around 1,135 to 2,270 m^3 (250,000 to 500,000 gallons) per hour and the irrigation of for example 80 acres can be completed in from one to two days. Unlike border check irrigation on this range of slope, which is for pasture irrigation only, Keyline Pattern hillside irrigation is also suitable for a wide range of crops.

For both these replacement methods the water is supplied from new farm dams by means either of a Lockpipe beneath the wall of the dam or by large-volume low-head pumping, according to the circumstances.

b) Contour bay irrigation

Contour bay irrigation is also widely used in Government irrigation projects. It describes the system that creates rice paddies, each paddy is a bay. It is most satisfactorily employed where slopes are some-what flatter with, say, a fall of 1 in 1,000.

Unlike Border Check the irrigation water supply channel preferably falls directly down the gentle fall of the land. The irrigation bays are again formed by earth banks and they extend outward and at roughly right angles from the irrigation supply channels and are constructed on a true contour. The bays are closed in at the ends lying away from the irrigation channel with a similar sized earth bank.

For irrigating, water is diverted through water gates into the first or highest bay until all the land of the bay is covered or flooded with standing water. Then the gates from the irrigation channel are opened into the second irrigation bay, the gates to the first bays are closed and gates in the lower bank of the first bay are opened. Thus the full stream from the irrigation channel and the water remaining in the first bay, flows into the second bay. This operation is continued through to the lowest or last bay. The irrigation channel itself is banked across at intervals to hold up the water and prevent it from by-passing the open bay gates. These banks across the irrigation channel are also equipped with water gates.

Land preparation costs are usually considerably lower than for the border check method. The irrigation channel may be wider and shallower. The banks for the bays are much larger. The distance apart of the contour banks is a factor of the vertical step between each contour bank and the slope of the country. For example: if the vertical step is 75 mm (3 inches) and the general down land slope of the irrigation area is 1 in 1000, the back up distance of the water will be 75 metres (250 feet). The contour banks themselves, although larger, are much more cheaply constructed by machinery using the side-casting method. The shallow ditch left by the removal of earth for the contour bank is usually left untouched and not "stopped" as is the ditch beside banks that are aligned down the slope of the land.

Contour bay irrigation from farm developed water resources follows in principal the above layout and procedures. Improvements come mainly from increasing the rate of flow of the water supply and increasing the size of the step between the successive contours.

(1) Design limitations of contour bay irrigation.

There is an inherent problem with contour bay irrigation in the fact that water in excess of the requirements of the soil in each bay must be supplied to the bay in order to back the water up to the bank of the contour bay above it. This water is normally used in the next bay below. The exception is the case of the lowest bay. Surplus water from the lowest bay can either be used by some other method, sent to a holding dam possibly by pumping or wasted. This problem is compounded as the depth of the water is increased.

Assuming that a sufficient flow rate is available that will allow the flooding and draining of the largest bay in thirty minutes the vertical step between the bays still reaches a practical upper limit at 500 mm (20 inches) because much beyond this, the pressure load on the water gate is too great for simple operation. In country with a general slope of 1 in 1000 the back up distance of the water 500 mm deep will be 500 metres (0.55 metres times 1000). The average depth of water in the bay, when the water reaches the upper bank, is naturally half of the maximum depth i.e. 250 mm (10 inches). By the time the bay is full of water, the porous topsoil under the sheet of water will be saturated to its capacity. The problem is, that there will still be enough water in the bay to water an area 5 times as great as the area of this bay.

If waste and tail water is to be minimised then the bays must be designed upwards in steps.

Supposing there is an area below the bottom bay that can be irrigated some other way with the surplus water from the last bay. This area will require about 50 mm (2 inches) of water to be fully watered. The average depth of the bottom bay needs to be designed to match this.

Each bay above this can be increased in depth till the practical maximum depth is reached.

Suppose the areas of the bottom bay and the area below it are the same. The bank interval for the bottom bay can be about 100 mm (4 inches) as this will give an average depth of 50 mm (2 inches) which is enough to water the area below. The next bay above this one can be sized to hold enough water for both areas below it. Each successive bay up the slope could be designed to hold enough water to irrigate all the bays below it. The bays are made progressively deeper until a design limit is reached. One limit is when the depth of water against the water gates reaches the practical depth limit of 500 mm as mentioned above. In all cases the vertical interval will be twice the average depth.

Watering the last section will be very slow as there is very little head of water available. Contour bay irrigation may be suitable for growing a very wide variety of crops, including orchard and pasture.

An alternative procedure is Keyline Flood-flow irrigation, where larger flows can be easily controlled by the one man, where land preparation costs are still lower and, most importantly, where drainage, often a problem of contour bay irrigation, is not a problem.

c) Furrow Irrigation.

Furrow irrigation is the most widely used system for the production of row crops and occasionally for orchard irrigation. On uniform and slightly sloping land, the irrigation channel lies across the slope of the land and the furrows fall directly down the slope at right angles to the irrigation channel.

The crops are grown on the small banks of soil between the furrows. Water is delivered via small pipes through the bank of the channel (head ditch) or more conveniently by placing numerous siphon tubes, (usually black poly' pipe), over the bank and so deliver water to many furrows at a time. The small individual streams follow the furrows downwards and thus water the crop growing between them. In circumstances where slopes are too steep for that layout, the irrigation channel may be on a true contour and the furrow positions pegged in with the aid of a level instrument to fall at a selected, slight grade. One furrow of each five or six may be thus placed, and those intermediately spaced, will be parallel to the adjacently marked furrows.

d) Spray irrigation

Certain advantages are claimed for spray irrigation, namely:

1. Uniform and closely regulated quantities of water can be applied on any type of soil, particularly porous and sandy soils which do not hold water well.
2. There is no land preparation costs involved, and with the absence of channels there is no "wasted" land.
3. It lessens the need for cultivation to control weed growth as against furrow irrigation.
4. Small area irrigation from small flows in streams, from little ponds, is possible for certain high value crops.
5. Soil erosion can be controlled on steeper hillsides.

The principle disadvantages to spray irrigation are:

1. Initial cost is extremely high.
2. It is unsuitable in windy conditions since the pattern of the spray is disturbed and watering is uneven.
3 Water must be free of rubbish and sand which will choke up the spray nozzles.
4. Power costs are extremely high because of the need to provide continuous pressure.

The spray method is frequently claimed as the most efficient in water use and often this reference is connected with Australia's "grave shortage of water". But, the crowning inefficiency of all was not mentioned. The inefficiency of capital outlay entailed when a method is applied in the wrong circumstances. Such inefficient use of capital is well demonstrated where a large farm dam is associated with the spray irrigation of only 6 ha

(15 acres) or so of land, where 10 days of continuous spraying and the moving of spray lines is necessary. In the same conditions of water availability and land shape a more appropriately chosen system of irrigation would have cost no more in capital outlay and have produced 20 hectares (50 acres) of irrigation land to be watered with a genuine high water-use efficiency in one day by one man. This better spending of capital is an efficiency ratio of 20 against 6 and a labour and time efficiency very much greater.

There have been continuing big improvements in spray irrigation equipment and, as there will always be circumstances where water is available and other less costly methods impractical, spray irritation will continue to play its role both in government and “on farm” water resources. However, since there is a plentiful supply of literature dealing with the various types of equipment and the differing procedures for spray irrigation, they will not be dealt with here.

4. Attitude to soil

Perhaps the greatest difference between Keyline and most other systems lies in the philosophical attitudes to the irrigated soil. Whereas the older, though still common, practices treat soil as if it was a static substance but also one which could deteriorate, Keyline regards any existing soil as essentially the home of an organic community of living things which can be improved to a much higher degree of fertility; biological fertility. The old way leads, for instance, to the practise of even reducing the small flows of the border check system in order to hold water in contact with the soil for longer periods, so that a predetermined amount of water is forced into the soil. Thus soil may be covered with slowly moving water for many hours during each irrigation and, to the great detriment of soil fertility because of saturation, water-logging and root suffocation.

On the other hand, on a Keyline irrigation project the basic aim remains that of developing the highest biological fertility in the soil. And a really fertile soil, when it is somewhat dry, will literally gulp water as fast as it can be applied.

If soils for Keyline irrigation are initially infertile, as they often are and as a consequence do not absorb water rapidly, then the soil is ripped or chisel cultivated before irrigation in such a way that the soil will quickly take in its quota of about 55 mm (2.2 inches) of water from each irrigation. This type of cultivation is done at times that are appropriate to the requirement of the individual soil. By providing, as it is designed to do, improved soil aeration and better living conditions for the soil life, the soil immediately starts to change and with continued care, soon reaches a condition of high fertility. Then, with the new sponge-like structure of fertile soil, it is capable of absorbing water rapidly.

Keyline Flood-flow irrigation controls the water and irrigates land much faster, and at a considerably lower cost, than other fully controlled irrigation procedure.

Water intake rate for irrigated soils, particularly in Government irrigation projects, is the subject of many tests and experiments with frequent reference in journals on irrigation. We may read that a certain soil when dry "takes-in" 12 mm (one half inch) of water in half an hour, but very little more in two hours; perhaps in ten hours it still won't absorb 75 mm (three inches) of water.

In Keyline we are not concerned with such times, but in how much water the soil will accept in the first 15 seconds, half minute, or ten minutes, and therefore with whatever techniques of soil treatment are necessary to make a dense soil absorb water quickly. Any dense soil can first be mechanically treated to cause it to take in two inches of water quickly. When one considers that compacted earth, when loosened for loading into a truck, often expands in volume by about one third, one can appreciate that in the same way the loosening of the top 150 mm (6 inches) of soil can create airspace and increased absorption, so the soil will quickly take in 50 mm (2 inches) of water. This treatment, when continued for a little time, will soon promote a new fertility in the dense soil and alter it to the sponge-like structure of highly fertile soil. Later with little further treatment, it will take in water almost as fast as it can be applied. A sponge plunged into water is hardly any wetter after 10 hours immersion than it is from 30 seconds to 10 minutes immersion, so it is that the sponge-like structure of a highly fertile soil permits the very rapid water application rates of the Keyline irrigation.

This type of cultivation is best done at times that are appropriate to the requirement of the individual soil. Then with improved soil aeration and better living conditions for soil life, the soil immediately starts to change and with continued care, soon reaches a condition of high fertility, with the sponge like structure of fertile soil.

IX. IMPROVING CITY DESIGN.

The basis of design for any landscape is the control and use of the water, which has greatest significance for the efficiency and aggrandisement of the landscape. On the farm there are two general water resource avenues; one is the water which flows from rain on the farm, the other is water which flows into the farm from outside it. On some occasions the most significant source may be water from underground.

The provision of household and stock water at several points where it is needed and where it must always be available even in the longest drought, is a subject for good design. But it is a flexible feature within the landscape and not a particular significance to landscape design.

A. Keyline Design in Urban Areas.

The principal water for city design, in like manner, is not the water supply for houses and industry but the run-off from rainfall and the wastewater of the effluent from within the city. This water is to move by gravity flow.

The first three factors of the scale of permanence have been named, ’the inseparable trinity of landscape design’, they are climate, land shape and water. These same factors are the special considerations for the selection of a site for a new city. Climate is continually the most discussed aspect of anywhere - it is always of importance. It is considered the most permanent factor of the landscape design.

Land shape will guide site selection by the influence of such matters as the size, lengths and slopes of the primary ridges and the size of the unit-regions and their association with regional unities. Land shape is second to climate in the order of permanence.

Water for the city is a consideration but it comes from outside and may be brought in from a considerable distance. City water must be reliable, pure and perpetual.

A great influence for the site selection may well be, in the first place, some geographical or geological feature of the wide landscape that offers particular advantages for city considerations.

The basis of design for the new city landscape is the same as for the farm landscape (farmscape), it is designed from the Keylines or the primary valleys that have greatest landscape significance.

The city should have a definite size and a boundary, which may be selected as an appropriately sized natural region. The boundary of the city may be principally the crest line of a large main ridge. The land for the city would first be surveyed and a contour map generated. The natural drainage lines and the natural water-divides would clearly display the natural unit-regions within ever-larger regions within the boundary of the design.

The flow of water of greatest landscape significance and design significance is the run-off from rainfall. While this flow in aggregate may be little more than that from city wastewater, the peak flows will greatly exceed the flows of wastewater. The average percentage of rainfall that becomes run-off from the natural landscape may be under 30 or even less than 12 per cent. But from the roofed and sealed areas of a city, rainfall run-off is very high. It is necessary to design for 100 percent run-off from the biggest storm rains.

New water lines would be added to the map in similar fashion to the diversion channels lines for the farmscape; but there is a difference in slope consideration: On the farmscape the gradient of the channels are governed by two factors, firstly, being made flatter than the creek below and secondly by being flat enough so that the flowing water does not wash out the channels in the earth. In the city these slope matters are critical. They arise from the movements of water that carries and transports such material as raw sewerage. They become the governing gradients and determine the lines of the design for the new city. These grades may vary in relation to rates and distances of flow that in turn determines the size of the underground conduits. The levels of population density for the designed city would be determined beforehand so the conduits and their special gradients and margins of safety, become a matter of routine for water and sewerage authorities.

The gradients for the lines of run-off control and for sewerage transport could be designed to flow at uniform depths below the surface of the land. These would be plotted in on the contour map. These lines for water control would not result in straights but would be made up of curves related to the contours of the land. Conduits for the main lines of a particular size would always lie at a set depth below the surface of the land. Sub-mains would be smaller and be at a uniform but lesser depth below the surface.

The notable visual effects of the roads would be the emphasis of the great beauty that resides in the natural shapes and forms of the land. The home sites would finally be arranged like seats in a great amphitheatre. They would also have the notable advantage that most of the roads are on or near the contour, which would be a boon for bicycle travel.

The layout of the new water-lines and their roads would divide the land into its characteristic zones as was illustrated for the farmscape. The higher land of the first zone would have a lower boundary related to the particular features and shapes of the primary valleys at their Keylines. But there would be other water lines within this zone. For instance the first of such lines would be located along the main ridge just above the first steep heads of the significant primary valleys.

The underground conduits for the two classes of water viz., rain run-off and sewerage, could be placed near each other and lie under a common road, or be some distance apart and have their own separate roads.

The principal road of the first zone would follow, as in farmscape design, along the crest line of the main ridge.

The new city, like all landscapes, is designed from the main ridges downward, and not as in the past, upwards from the shorelines and the river lines.

The second zone would lie between the lines of control and the lines for the use of the rain run-off water. The run-off from the two higher zones would be directed to ’city forest’ areas located in the third zone - the zone on the farmscape that contains the blocks of irrigation land.

The sewerage treatment works, which remove the clutter of the larger solids and grease, and partly cleanse the effluent, would be located at selected places along the lower boundary of the third zone. They would discharge their final effluent to irrigate the ’city forests’ located in the fourth zone. The various water lines would then be connected by pipelines, with valve control up and down the selected primary ridges. Their roads would lie above them.

In the Keyline Scale of Permanence; the first two factors of the scale, climate and land shape, have aided the selection of the site for the new city. The third factor, water - and the control and the use of the water of greatest landscape significance - has laid in the broad and basic water-line design of the city. The other water - for city homes and industries - is brought in from outside by pipeline via pump or gravity flow to be delivered to water towers located on the hills of the main ridges. The present manner and considerations for its supply are fully adequate.

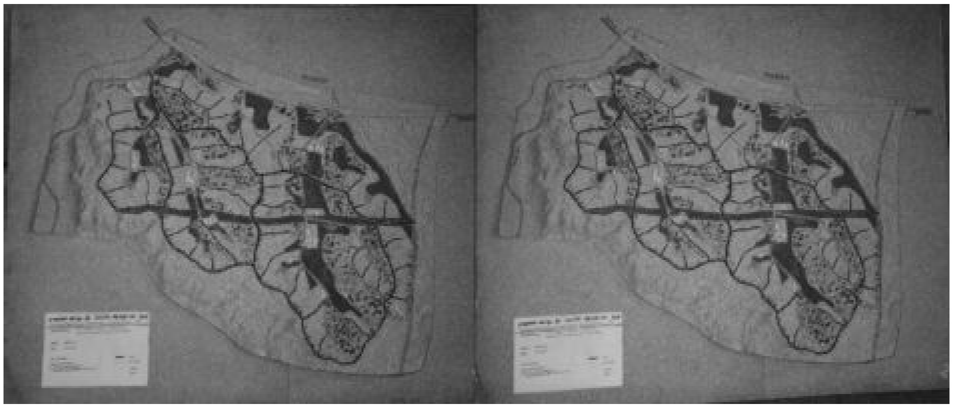


Plate 12 This image is a stereo pair. It is a relief model of an urban development proposal, which was done by landscape architectural students under Professor Elias Duek-Cohen at a Sydney University. The Professor saved the model and Ken Yeomans was able to obtain this pair of photographs.

To see the model in 3D without special viewers is a skill that can be learned. Either past the image so your eyes are parallel left eye on left image and right eye on right image or the left eye must look at the right image and the right eye at the left. To do this one must go cross-eyed. If you need a strategy to do this try holding your upturned thumb near the screen. Position it midway between and slightly below the two light rectangles of the map legend. Focus on your thumb and bring it steadily towards your face. As you do this the screen image becomes doubled so four rectangles will appear in the background. Keep your eyes trained on your thumb coming towards you. As you progress the middle two rectangles of the four will start to come together. Adjust the sideways tilt of one's head to line them up. When they fully overlap allow them to merge into one rectangle. This merged image will be in 3D. Allow your gaze to drift to the rest of the model and it too will appear as a 3D image. Have fun!

The fourth factor of the scale, roads, have followed along the uniquely located water lines to provide their service access. They have connected up the main ridges and the new zones of the landscape. They have added the final lines to the anatomy of the cityscape.

The fifth factor of the scale, trees, have been located to use for the benefit of the landscape, the rain run-off and the wastewater of the city.

The sixth factor of the scale is buildings. On the farms they are the homesteads that are the centres for control, administration and management.

The sixth factor for the city design is the location of centres for control, administration and management. The locations of these centres fit into the overall pattern of the waterlines, the roads and the city forests, so that they all serve their particular purposes.

The seventh factor of the scale of permanence is subdivision.

The design thus far is skeletal and on the surface is illustrated by the interconnected system of roads, run-off water holding areas at the keylines of the selected primary valleys and the layout for the city forests. Appropriate water lines, roads and streets further subdivide each of these separated areas. The rain run-off from every road and street and from the roofed and paved areas, and the wastewater of the sewer lines from homes and buildings, are guided to their special underground mains to flow by gravity to their proper places. Such designs in detail within the design of the cityscape are the province of the municipal councils, the planners and the architects.

Soil is the eighth and last factor on the scale of permanence and its importance will be detailed in later chapters.

B. Review the New City.

What has this design achieved? What if any, are the benefits for the cityscape and for the people who will live there?

Firstly it has ensured a logical and forward planned sequence of developments, natural region by natural region, which can be studied on paper and fully understood by the many divergent professional peoples from sociologists to engineers and from biologists to architects who must play their parts in the countless, final and detailed designs within the framework of the city design. Each can appreciate the special province of the other and reach agreements and decisions more readily. A wide unity of purpose would be an expected result.

Construction and engineering aspects of the design ensure that the major waterlines with their roads do precede other developments, as they should. The locating of underground mains at uniform depths below the surface is efficient and economical, particularly by comparison with present city practices where the placement and servicing of these mains turn many cities into vast underground mining operations where excavations are often very deep and pumping stations innumerable. Moreover, other service mains which are not dependent on gravity alone - city water supply, electricity, gas and telephone - would be associated in a practical manner with the water design lines. Each would have its appropriate and regular place in relation to all others, to be tapped and serviced with simplicity and expedition at low cost.

The major new divisions of the land into zones by the gravity flowing water lines and their overhead and interconnecting roads, offers opportunities for rational subdivision into suburban areas and for subdivision within the suburbs. The excellence of many facets of design within the present cities, but which exist now only as disconnected and disordered mosaics, would produce in the new city, an overall harmony of efficiency and beauty.

The first zone of the main ridges with its principal roads along the crest lines is the place for many of the centres of administration and management, the sites for the cultural and commercial centres.

The fourth zone that is along and above the shoreline and the drainage lines of the streams is a critical zone for the balance and health of the wide landscape.

This is the zone for the principal sports and playgrounds, of the larger parks and gardens as well as sewerage treatments and city forests. Treatments works will be as compatible with sports-grounds as toilets are with gymnasiums; everything is clean. This is a CLEAN city, where wastewater treatment works have trees in mass surrounds. The water which moves to the rivers and harbours from the soil of the city forest will probably be better than the water stored today in the great supply dams on the rivers.

Indeed, the natural regions that collect the water for these dams should be designed on the same new water lines, so that all the water goes into special cleansing forests before it can reach the streams and rivers to flow to the storages.

The major effort must be the design of “City Forests” on areas of land immediately outside the city, and the delivery to them, via pump and pipeline, of the effluent of the city.

The effect of this measure would significantly reduce water pollution. It would also reverse the process of oxygen depletion of waterways caused by effluent, which, wherever they go, destroy the balance of water-life by over-stimulating the slimes and the algae. Over-stimulated to death - in their decay they use up the oxygen of the water to cause the death of myriads of small animals and great numbers of fish that likewise in their decay, further reduce the water's oxygen. These effluents have already caused the death of great fresh water lakes.

Sewerage treatment works will discharge their effluent to irrigate what must become the fastest growing forests. Stimulated by the products that remain, even in effluent which appear crystal clear.

Of all landscapes, the greatest bulk of luxuriantly growing living matter may well become the effluent irrigated city forests. Therefore city forests must also be important biological research centres. Because there may be certain trees in the world that can concentrate one or other of the harmful substances now in the environment, every kind of tree should be grown so that their wood could be analysed and such special properties discovered.

The fourth zone of the land protects the common waters and the atmosphere. There are to be no unnecessary intrusions into it but there will be public enterprises that are essential for the living and the workings of the city. Even these special facilities, where possible, must stand back from the water's edge and the shore line, so that the water they shed and the wastewater they release can be collected and pumped back to the mains along the upper boundary of the fourth zone, to be processed and reconstituted in the 'city forest'.

Many of the larger industrial complexes now intrude into the land of the fourth zone because of the ease and low cost convenience of getting rid of their obnoxious wastes in water by dumping them directly into the streams and the sea. They would be excluded and positioned in the second zone, where they would, if necessary, carry out the first processing of their wastes before it flows with the more normal city wastewaters. Since the contents of wastewater are valuable, design for profitable extraction will continuously emerge. Where the size of such undertakings and their effluent discharge warrants, their individual design should provide for their own treatment works and forest. These businesses would soon learn ways to make both profitable.

Present large cities cannot be redesigned or altered quickly to substantially improve the efficiency and economy of city functions. It is too late for that. They are more likely to become less efficient and more costly until, if and when, they cease to grow. But growth could be stopped and a new city designed nearby, but divorced from the function of the present city, except for the joining of the two by roads, public transport and communications. Who could doubt that this would be the best for the larger cities and for the great majority of their citizens? The provision of those facilities that now lag behind population demands could catch up. Progressively rain runoff water control could be applied in the more critical areas and the water added to effluent movements to the City Forests. Although the efficiency of the city operations are not improved immediately, great environmental amelioration would be achieved. The city would cease to be a major contributor to environmental destruction.

What of the high cost of city land which would be used for growing forests? The cost of the land for a new city would be low. Only when people live there and other people want to live there does such land become valuable. It is more valuable when the facilities for homes and for industries have been completed at low cost efficiency in roads and the service lines beneath the roads. So why shouldn't a new city compete with older cities by offering clean air, good water and fertile soil and far better living, social and working conditions, as well as cheaper and better land for homes and industries?

The land of the several "city forests" will receive all the rain runoff and wastewater from the city to use and reconstitute and it must continue to function even when it rains for a fortnight. To ensure its capacity in this direction and for economic reasons, dams for holding run-off rainwater temporarily, would be located at the Keylines of selected primary valleys, as in the farmscape. Concrete lined, they could be kept empty. The first rain run-off after a dry period carries with it greatly increased amounts of oil and other matter. The empty dams could be used to store this first flow, so that it could be cleaned when necessary. Even so, because the water goes in at the top and comes out at the bottom, the oil wastes which float and others which sink could be trapped and retained in the holding dams for treatment, sale or disposal after the rain has ceased. The dams would have controls, which either turn the water into the dam or divert it around to below them. The bugbear of local flooding, which now occurs with each heavy storm, would be avoided.

A city forest is a multi-forest. Firstly the various species of the trees would be selected for their ameliorating effects on the air, the waters and the soil. Secondly the selection of the tree species could be based on economic considerations. The city forest is designed to be a working perpetual forest for the profitable production of fertile soil and valuable timber with the added benefit of the elimination of the need for ocean outfalls.

Chapter Fifteen (XV) is about trees and has more on the “City Forest”.

Let us now consider the basis of Keyline land planning and how this stems from a basic understanding of the natural form and shape of the landscape.

X. DROUGHTS, FLOODS AND CONSERVATION

While it has been stated that Australia is not short of water on any comparable per capita basis, the incidence of rainfall is very unreliable. Because of our geographical position on the globe, a succession of droughts and floods, characterises our climatic conditions. Whether it be good or bad, this particular climatic feature is the background to all our agricultural pursuits and it is therefore a principal factor in any planned development of land. Also the now ingrained obsession with "conservation" remains as a disturbing problem to overcome, before all our land can reach its peak of development.

Droughts and floods are invariably coupled together and they are the major parts of the one climate. Droughts are uncontrollable and will always cost a lot of money, floods on the other hand represent neglected opportunities.

Floods following droughts are worsened by the inability of the soil on which the rain falls to take in the water. A simple drought strategy is to prepare the property for rain. Loosen the soil, check all the channels, the rain will come.

A. The flood rains of Victoria and N.S.W.

The rain which causes the floods in New South Wales and Victoria are of the order of a total of 250 mm (10 inches) which usually occur in two series of falls, one following rapidly upon the other. At least 70% of this 250 mm (10 inches) of rain represents, "opportunity" rain which could be put to good use if the control structures, for water resources development, existed on the majority of farms. It is on the farms where such structures would be appropriate.

Severe droughts tend to be broken by flooding rains and this is all to the good since the end of the drought finds on-the-farm storages carrying their lowest reserves of water.

What would happen if a drought broke with a fall of 250 mm (10 inches) of rain on "Nevallan" and "Yobarnie", the original Keyline properties?

Firstly, 75 mm (3 inches) and most probably nearer 100 mm (four inches) of it would have been absorbed rapidly by the good soil of the 240 hectares (600 acres) of very dry rain pasture land. Possibly a little less would have been absorbed by the 200 hectares (500 acres) of land which we irrigate. By this time the two, small, normally dry creeks, that enter the area would have started flowing and filling the dams located on them.

After the first 75 mm (3 inches) of rain, run-off from the land of the farm itself, would commence and be trapped by the diversion channels and flow into the two series of interconnected dams which these channels service. The lower of the two diversion channels on “Yobarnie”, which also diverts the flood flows of the small creek, would start to receive water from the overflow of the lesser creek storage and start the more rapid filling of the first of the next four dams on this channel.

By the time 180 mm (7 inches) of rain had fallen, the lower series with its larger dams would be filled to the last dam of the chain, which would then be close to the point of overflow. In the meantime, of the higher series of dams, four of the six would have filled with their overflow filling the two remaining dams. The continuing flow from the rain so far received, would fill all but two high dams, which are above the chain and which are finally filled and later on replenished from, a permanent pump and pipe line from the larger of the creek storages. One creek dam would have been long since filled and the full flow of the water of the creek would be returning to the creek below the dam.

There would also be a considerable flow of water leaving the property in one creek which is uneconomical for us to control.

The channels and dams are patrolled on such an occasion as this and with several dams filled, the overflow points and the lockpipe valves would be opened to reduce the flows in the diversion channel. Creek dam lockpipes may remain open for some two days or more to reduce and then to stop the overflow in the spillways. Of the 250 mm (10 inches) of rain the run-off from the land of the farm itself would have contributed little to creek flows lower down, but a considerable volume of water from outside the farm would have flowed on through the property.

A day of sunshine following this 250 mm (10 inches) of rain would give an appearance to the farm as if it had received a nice shower of rain the day before, except for all the filled dams and the water still flowing gently in some of the control channels. As the following image shows.

Plate 13 Yobarnie from the air showing how Keyline design utilizes run-off from what are called the "damaging-flood-rains" in Victoria and New South Wales. (Google Earth 33°35'S 150°42' E)

B. The summer flood rains of Queensland

The summer flood rains of Queensland are an entirely different matter. Here the flood-causing rains are likely to be nearer 500 mm than 250 mm (20 than 10 inches) and so the control and storage of the major part of these rains on farm and grazing properties is somewhat more than an incidental, in farm water resources development. Flood rains of such great proportions can not be all brought under control at a profit, either privately from the land owners point of view or nationally from the viewpoint of the tax-payer. The only logical way to handle this situation is that as much of the rain be controlled and stored on the farm and grazing land as is both practical and economical and that the rest of the water flows to the sea. But such is the appeal to the compassion of our people when the disaster of flood causes houses to be destroyed and personal belongings to be washed away and lives to be lost, that funds to assist the victims of the flood are invariably forthcoming. Calls for massive “flood mitigation” then break out as if by infection for a few weeks.

But if public works for flood mitigation are to be undertaken it would be better that the money be spent in assisting control of these waters on the farm instead of trying to control the water after it has reached the river; since then whatever is done must still be too little as well as far too late.

C. Comparative losses from floods and droughts.

Floods cause heavy financial losses which are borne by an unfortunate few. But these losses are quite minor from the national aspect and particularly so when they are considered against losses caused by drought.

While comparatively few farms suffer losses by floods, a large number are greatly benefited by the same rains. But during drought this position is reversed. The vast majority of farms and grazing properties suffer severe losses, some owners even to the point of the losing their property, while only a few are fortunately placed to benefit from the disaster.

If it were deemed necessary to make up the losses caused by floods to the owners of flooded land, it could be done with little effect on the public fund. But losses from drought are of such a high order as to be quite outside the scope of such assistance. Droughts and floods cost money but what a difference in price!

Drought cannot be controlled. But as far as the individual owner of land is concerned, by the full development of the water resources of the farm, he may be able to change the order from six fair years and then one of near disaster, to six very good years and then one lean year.

Artificial rain-making does not appear to be a possible answer to droughts since there have to be suitable clouds on which to operate and these are rare in drought times. However, if these experiments were directed, and showed promise, at creating the cloud when there was suitable moisture in the atmosphere above the dried out land, and this moisture was of much more frequent occurrence, then there may be some prospects of success.

D. Keyline compared to Soil Conservation.

Soil conservation is a misconception of the relationship of land and its water and soil. Those who understand Keyline naturally recognise the futility of the philosophy of soil conservation, its techniques and the manner of its segregation from being a branch of agriculture.

Surely the principal objective of all rural land planning should be the control of water for beneficial use and to produce a better landscape with permanently improved soil.

Modern soil conservation was born of panic and pessimism in the depression days of around 1930 in America and had two basic foundations:

(1) The most rapid decimation of soil in the history of civilisation, caused by the failure to adapt the farming traditions of the older lands to the

very different conditions of soils and climate of the New World, and

(2) the worst and most strange financial depression in all history; a depression which, in the midst of an over abundance of foods of all kind as well as most other goods and services, organised society was unable to feed and clothe its people. So they starved in the richest country on earth through a deliberate policy of financial credit restriction intended to achieve a centralisation of power, both political and financial, hitherto unacceptable to the ordinary citizens of the United States. The financial policies that created and sustained the depression had a pivotal role in the destruction of the landscape.

The second foundation of the soil conservation drive was the most activating one. The Government borrowed[5] newly created financial credit from the private banks and this credit (with debt and interest accumulating) was used as the means of getting the economy of the country operating again.

Innumerable books were published to arouse people to the menace of erosion. Soil erosion control, or soil conservation, developed to the status of a new science. Text books were produced. The unemployed were mobilised, though only to do the bidding of the Government. Thousands of men were trained on a crash course to become experts who would control and direct half a million soil conservation workers. For instance, one United States Government agency was formed to manage and supervise 80 million acres of public grazing land. Another was set up to purchase land too poor to afford a living for the farmers and turned into wild-life sanctuaries, forest and recreation areas while the dispossessed populations were transferred to better land. The Civilian Conservation Corps at this time employed half a million men. Such were the huge money resources involved.

In the United States, a thorough advertising and public relations campaign gave the people a veritable brain-washing on soil conservation, emphasising that their method was the only answer to the menace of soil erosion. This campaign developed to permeate most of the world farming regions.

Plate 14 A scene all too common. Soil conservation contour banks to safely dispose (waste) runoff water. Windmill lifts bore water for stock to drink. Isolated trees provide little shade.

In 1943, P. A. Yeomans[6] was an enthusiastic soil conservationist, and on taking over the property at Richmond in New South Wales, immediately commenced to fight the soil erosion which was evident everywhere on this land. He had built his first earth dam in 1939, studied soil conservation for some years and had construction equipment including bulldozers and giant scoops on nearby mining and construction jobs. Therefore, he considered himself well equipped for the work of soil-conserving the property although he had no direct experience of farming and grazing.

However, his brother-in-law James Barnes was well experienced on this side and was going to live on the property and manage the project.

With the start of work it was found that each technique of soil erosion control that Yeomans knew so well, was not effective in improving the fertility of the soil.

There seemed also to be no logical starting point anywhere or basis of planning in soil conservation. But because of the need to store water building dams was a first necessity. As Yeomans' earlier dam building experience had been for mining purposes and with dams larger than ordinary farm dams, it was decided to build our farm dams much bigger than usual and irrigate from them. This gave us a logical new use for the "contour drains" of soil conservation techniques which was to collect water to fill the dams. The weather at the time was dry and hot and in December 1944 high winds drove a distant small fire into a general bushfire. The properties were burned out and James Barnes lost his life in the fire.

The project was continued on the basis that we would try to make all the poor soil into good soil; and as we needed all the water available for this purpose we would catch extra rainfall in the soil and store all the run-off for irrigation purposes.

Plate 15 Keyline irrigation dam and stepped tree belts.

The whole point of this brief recital is that P. A. Yeomans had changed from a "soil conservationist" into a "soil developer".

The problem of changing poor soil into good fertile soil was solved and the continued irrigation experiments led to new methods for hillside land that were very much faster than our spray systems and less costly in both capital outlay and in manpower.

Plate 16 As visitors look on, Rix Wright, "Knockalong" Delegate, N.S.W., turns on the tap of the Lockpipe System to release the stored water from his Keyline irrigation dam.

The futility of the conservation approach was gradually realised and later stated, in various Keyline publications, public meetings and field days. But such is the power of continual publicity and suggestion that we at first considered we were originating new methods of soil and water "conservation".

We were doing what all soil conservationists do to this day. We were making the word conservation mean something totally different.

Very early Yeomans realised this mistake and logically opposed the whole concept of soil conservation thereafter.

In Australia, with its generally poor soil and unpredictable rainfall the word conservation is an illogical reference, which should now give way to the more practical approach to soil and land "development" including, as its main planning basis, "on farm" water control.

Plate 17 People follow the water as it appears to climbs out of the valley on its way to the irrigation area. Cars are along dam wall.

If the Department of Mines was named the Department of Conservation, this would be a practical usage of the word, since every land should “conserve” those things which when used up, wasted or lost, are gone forever. Conservation might correctly apply to such things as base metals, minerals of every kind and our oil and natural gas. Applying the word conservation, and the philosophy associated with it to soil, and water that are alive or self-renewing, if we permit them to be, seems now as out of place as it would be to describe the world famous “Haddon Rig” sheep station in North Western N. S. W. as an outstanding example of sheep conservation.

However soil, water and forests cannot merely be conserved and at the same time be made to fulfil the needs of Australia. Soil must be improved, made more fertile, more productive and be housed in an improving landscape. This is necessary for its lasting fertility.

All our water resources should be examined for development and use, strictly on the basis of economics which should determine the course of this work and the priorities. We just cannot afford the waste of our manpower and other resources on uneconomic development. There is far too much to be done!

Plate 18 The water arrives at the first irrigation flag. Some people will need to move soon or get their feet wet.

Plate 19 The people in the irrigable area below the channel are standing ahead of the sheet of water. The others are on the top side of the channel.

Plate 20 The irrigation flag blocks the flow and water spills from the channel onto the Keyline Pattern Cultivation and is spread sideways.

Plate 21 Mr. Rix Wright shares his Keyline experience and insights with his visitors.

Forestry is not conservation, particularly not in this country where it has been a function of Forestry departments to destroy the trees on tens of thousands of acres of naturally wooded lands which are covered with worthless timber, in order to plant new forests of trees for better timbers. This surely is Forestry development as it should be.

The earlier soil conservation concepts of land usages according to certain carefully tabulated land classes, have presumed that the best which could be done about any soil was to maintain it in its present condition and not to lose it by soil erosion. There is even now no general realisation that all soils can be tremendously improved, or that merely saving poor soil is scarcely worth while.

The only sure and economic way to prevent soil erosion is by forgetting it and concentrating on soil and landscape development.

By the mid sixties, the most populous of the Australian states, New South Wales had developed a soil conservation service for a quarter of a century. This service had cost, by then 10 million pounds (equivalent to about $200 million early 1990’s Australian dollars). Yet none of its farm projects or any of its service-owned and costly demonstration farms exhibits a proper basis of land planning or design. Why is this? It seems to be that the misconceived philosophy of conservation precludes the possibility of any method based on it from being the best way to improve the land. A great deal of money was spent less effectively than it could have been.

Planning based on defence always fails. It is fore-doomed when it comes to defence against soil erosion, since the objective is not basically worthwhile. Moreover the earthworks that remain when soil erosion stops, and it can be stopped if the money is spent, remains as a positive handicap to the full improvement of the whole property landscape.

It is time for Governments in this country to reconsider the policy and administrative directives of the departments of agriculture and those within the Conservation Departments, of water, forestry and soil.

It is time to initiate completely new and more logical policies of planning and development based on Keyline principles[7].

XI. DESIGN OF FARM WATERS - AN EXAMPLE.

A. Examination of water potentials.

This discussion may proceed on the assumption that we are dealing with a property on which there is one or more complete water run off systems. A system in this context meaning an area of land on which there is a main ridge with its series of primary ridges and valleys falling from one side of it to, and including, the water course below. It is further assumed that it is a property of 500 hectares (1,250 acres) of land which is of a medium undulating and smooth character that, while generally being short of suitably spaced rainfall, does have an appreciable run off at completely unpredictable times but usually once and sometimes three times a year. At the same time, the variations of any plan which may be necessary if the run off were very much less, will be mentioned. Also it can be assumed that the only information, other than that from the farmer's own observations and experience, is that the minimum annual run off is only 50 mm (2 inches).

To begin with this minimum annual run off represents 250 Megalitre s (200 acre feet of water [or approximately 55 million gallons], an acre foot of water is 272,250 imperial gallons). A minimum annual run off of anything at all is a favourable position to be in, since the average annual run off must be considerably higher and the maximum run off which may be expected once in say each three years, could then be very considerable.

The owners of agricultural land are more likely to go out in heavy rainfall than those who follow other occupations. They would be more in a position to observe the high run offs from the valleys of the farm and the state of the flow of creeks and other streams which follow the rains. This information, if the farmer has been thoroughly observant, is the most valuable that is likely to be available to him for the planning of the control of these waters.

B. Diversion channels for water control

The run off from the property itself is, in the circumstances so far projected, quite significant on its own for development. The next point to consider is the flow-in water of number 3 category. The first three water categories of Keyline are: 1: Absorbed rainfall; 2: Run off within the property; and 3: Water entering through the boundary. (See Chapter VII for details). If the small creek flows intermittently and carries considerable flows after rainfall, it may bring to the property much more water than all the water of number 2 category rainfall run off from the farm itself. It is therefore examined as to the possibility of either storing the water flow in large quantities at the nearest suitable site to the point of entry, which is the highest site, or controlling the water to divert the flood flow through the property and for storage at sites in some of the primary valleys selected for the purpose.

If the course of the creek through the property is somewhat rocky or of an uneven bottom with the stream flowing as a succession of rapids and small ponds, then the fall of all the land itself will most probably be sufficient to permit diversion of the water from the creek near where it enters, to fill properly sited dams.

Where these conditions exist, the site for the control of the flood flow of the creek and of the diversion channel itself, becomes the first fixed sites and water lines (the channel) of the plan for development of the property. At this time a line could be surveyed with an automatic, dumpy or Bunyip level and be progressively pegged to show where the diversion channel would lie. To do this, a site would first be chosen for the level at which the water would be diverted.

Since the diversion of this creek water would be accomplished by a dam and spillway at the most suitable spot, the level of this spillway would be the controlling level for the pegging of the diversion channel course, down through the land. In undulating country such a channel should be given a set rate of fall, and 1 in 300 has been found as steep as is necessary in almost every circumstance.

The fall given to a main water diversion channel for this purpose, would be very much less than the average fall of the creek through the property. As the diverted water progresses along the channel through the property the creek looses its height faster than the channel. The result is an increasing area of land below the channel, and between it and the creek. The water may appear, to some, to be running up hill.

This feature is of great importance since it may allow dams to be constructed to receive this flow and store this water. These dams will eventually command areas large enough for low cost gravity irrigation. When they command areas large enough the dams are equipped with an appropriately sized (300 mm through to 600 mm diameter) Lockpipe system for low cost

gravity irrigation.

1. Water storages located by diversion channels.

Because the starting height of the diversion is not on the bottom of the creek, but to the side and on the creek bank, the pegs set with the aid of the levelling instrument will progressively leave the creek as more pegs are set. Pegs should be placed at a fixed interval apart such as 15 or 20 metres (50 feet or one chain). The pegged line will soon cross the lower end of the first of the primary valleys. The position of this first valley is the least likely one to be suitable for a storage site having land for irrigation below a dam constructed there, but it may happen to be a very good storage site from which water could be gravitated to land further along. If this is so, then at this time a decision should be made as to the most suitable wall height for a dam if one were to be constructed in this site later.

A wall which will hold a depth of 7 metres (23 feet)[8] of water above the level of the valley floor at the wall site is generally very suitable for medium undulating country. Where the land is much more gentle as to slope, a lesser depth of water may be decided on.

Some of the critical matters to be considered in the selection of sites for storage dams and the heights of the earth walls are discussed below and in following chapters.

Suppose a 7 metres (23 feet) dam is envisaged. The top water line or top storage level, (TSL) of the dam will usually be designed somewhere between two limits. (1) With the top storage level coinciding with the height at which the diversion channel reaches the site, or (2) with the top storage level at the height at which the diversion channel leaves the site. An advantage of this latter option is that the diversion channel may be constructed to operate completely independently of the site. Water can be allowed to bypass the dam or be diverted into it. If, as is often the case height is of the essence, then the point where the diversion channel enters the site can be chosen as the top storage level of the site. This choice saves the height loss that will occur in the channel as it traverses its way around the valley, the main problem is that it is not possible to get the water past the dam until it is full. When the dam is overflowing water also backs up the diversion channel.

If designing in accord with the second option, select the peg along the diversion channel (after the line has descended through the valley) that is 7m (23 feet) above the bottom of this primary valley directly below the peg. The ground level at this peg will represent the top water level of the suggested dam. The dam is positioned completely under the height of the channel and the two water lines coincide only at the overflow level of the dam.

In either case the water line of the dam should be pegged. Firstly a special distinguishing marker, such as a longer peg or steel fence post should be set to mark the initial place. This is also the height of the spillway (overflow or by-wash) of the dam. At this stage a true contour line may be pegged around the primary valley to mark out the complete top water line of the dam.

Between the two places on either side of the valley where these water line pegs reach 7 metres (23 feet) above the valley floor, would lie the centre line of the dam wall.

This pegging out immediately permits a full appreciation of this position as a dam site, since the land owner can now make a quick estimate of the area enclosed by the contour line round the valley and the line of the wall. This area in hectares, is multiplied by the 7 metre depth of the dam and then multiplied by a factor of about 3.7 (from 3.3 to 4). The product is the approximate capacity of the dam in Megalitre s. (If you prefer imperial measurement: the acreage multiplied by the depth of the dam feet, and multiplied by a factor of around 0.37 (or say 1/3 to 2/5) is the approximate capacity of the dam in acre feet.) With a little further surveying and estimating, the farmer can also know the volume of the wall and the approximate costs of the earthworks to construct the dam.

Continuing from the wall peg placed on the far side of the valley and resuming again the same rate of fall, the line is continued in this manner to, through and beyond the last primary valley of the system. On the way each valley can be appraised as a site for storage. The land below is observed to estimate the area which would be suitably positioned for gravity irrigation, critical distances, such as the increasing length of each successive primary valley lying below the pegged line to the creek below, are noted. A great deal about his land is learned by the farmer in the course of pegging this “new” water line.

Every shape and form of the land is emphasised by just this one line and often to the extent that the owner will realise for the first time something of the hidden potentials of his own land.

C. Choosing of first water storage site

To continue with the description of this water of category three; let us assume that there is more than enough water flow to fill all the suitable dam sites. The owner is now in a position to choose the first site to be developed. Any position on the pegged line can be selected for this purpose the main consideration being that it is associated with an area which can be most quickly prepared for irrigation; that is the dam site and land associated with it, which will return its cost most quickly.

Lines for water control and the storage sites themselves are critical, because all other factors of a plan are decided in relation to these basic lines. The next information required, will relate to another aspect of water control, namely the more exact position of the irrigation area associated with this dam which is likely to be constructed first.

As the dam is to be 7 metres (23 feet) deep, a peg position in the valley below is determined. This is the starting point of the irrigation channel which would carry the water for irrigation. It is lower, by the depth of the dam, than the channel line peg which represents both the spillway level and the centre of the wall of the dam.

The irrigation channel falls with the land, which is the direction of the creek fall, as does the diversion channel itself.

From this irrigation channel peg, a line falling at 1 in 300 is pegged with the aid of the levelling instrument and continued right around this primary ridge at least to and just beyond the next primary valley. Since all the land below this line to the creek below will be commanded by the irrigation channel line just pegged, an estimate can now be made of this land as an irrigation area.

The first located main diversion channel will not only carry the flows diverted from the creek, it will also collect the rainfall run off from the land of the farm which lies above the channel and throughout its length. This run off water from the farm is, in this instance, of such proportion as to warrant control and storage for use in irrigation, even if it is assumed that the soil improvement program and then later, the improved soil itself, will take its own quota.

The next information which is required is the relationship between the different Keylines of the primary valleys throughout the system. In this examination those primary valleys which have shapes that are of likely significance for water storage are the principal ones considered here.

D. Water and the Keylines

Inspection may start from either end of the system or it may be undertaken from a particular primary valley which appears to have the best shape for a dam site. The Keyline would then be levelled in and pegged around the valley to represent the water line of the storage; as is already described for the dams on the creek diversion channel. Estimates could be made on the spot of the water holding capacity, the volume of earth for the wall of the dam and the cost of earthworks. Then a second line for a new diversion channel would be pegged from this dam and rising at the set gradient towards the rise of the country. Eventually the full extent of the induced catchment area could be determined. This line rises into the higher country from the dam site, and becomes the line for a water collecting channel for the dam. When the pegged line reaches the next (higher-in-the-series) primary valley, this valley is examined as to its suitability for water storage. If it is entirely insignificant for this purpose, the pegged line may be continued around the primary valley and on to other valleys which can also be examined as shown earlier.

Because of the rising relationship of the Keylines in adjoining primary valleys. The pegged line will probably cross through a valley at a point below the Keyline of that valley. The pegged line stays below this Keyline and does not step up and continue from it. The worthwhile result is, that the line stays somewhat lower and so has the maximum area above it to supply run off water to it, then finally to the dam.

If a later primary valley has a shape of significance for water storage the pegged line is terminated at this valley at a point which is usually somewhat lower than the Keypoint of the valley. The Keyline of this valley is then pegged as a true contour to disclose the details of this possible storage site and if it is satisfactory, then a second rising line is started from this dam site near, if not from, the Keypoint of the primary valley and continues into the rise of the land as before.

All these primary valleys are examined as to their possible storage sites at their Keylines and the relationship in height of their respective Keylines.

A principal consideration is, that the final results should be two or more inter-connected storages in which the overflow from the highest dam is caught by the water collecting channel and directed to the next lower dam and so on throughout the chain of dams. If on occasions the sites, as first selected, do not quite conform to this pattern, then a little adjusting to raise or lower a dam site by a metre (few feet) or so, and the gaining of a little height by slightly flattening a drain throughout its length, should be done. An unnecessary break in the chain, which may prevent the overflow of a dam reaching the next dam further down-land, or a break which divides what should be one chain into two smaller chains, cannot but reduce the efficiency of the system.

E. Gravity control of stored water

There are three likely avenues of gravity use in irrigation for the stored water of a high chain of dams located on this pattern, as well as any method of spray irrigation where this is appropriate.

Firstly, if there is sufficient land lying below the Lockpipe outlet of any dam and above the creek diversion channel, which lies below this higher system, this land is irrigated via an irrigation channel.

Secondly, the water may be used to irrigate the strip of land lying immediately below the creek diversion channel. This is less likely unless the country is “short slope” in nature. The water must be directed down, then through the bank of the creek diversion channel. Once the irrigation stream is below the creek diversion channel, it can be used to water this normally dry strip of land. Once below the creek diversion channel this water cannot get past the next dam without loosing height to that dams irrigation channel.

Thirdly, the water may be used to provide extra water to a dam on the lower chain, thereby increasing its irrigation capacity.

The water lines for the two types of channels (diversion and irrigation), now become the principal planning lines for the full development of the property.

Plans for every other feature are fitted into this design.

1. Channel lines remain the same for less water

Another aspect of this planning relates to the lack of reliable information on the water available and the necessary approach to the undertaking if there was considerable doubt as to the water potential, or the water was much less than is indicated by these earlier comments.

The owner would first have to decide from his own observations and local knowledge whether the creek flow was such as to fill satisfactorily at least, one dam instead of the whole series of them. Even if he was sure only of the water for one dam, the planning and pegging would still proceed exactly as before, except that, while every likely site is appraised as has been described, only one site would be selected for dam construction.

This site would be far enough down the property for suitable land to lie below it for irrigation if possible; the site would be chosen for economy and one that is capable of quick development and good financial return.

Similarly with the appraisal of the sites higher in the primary valleys, the owner may be confident that the water available could be managed by only one dam.

The appraisal of these various sites in this case would be similar to those mentioned before.

The particular factor to be noted, is that the principal water lines which will influence the whole planning layout are the same for both sets of circumstances.

Later when this lesser scheme is developed and working well, it may be found that there is more water available than was expected, which this limited layout can use. Then it is a simple matter to add more storages on either water line channel, by fitting them into their appropriate relationship with the particular channel. The critical factor in this rearrangement is that the top water level of any new dam should coincide with that of the diversion channel on the down side of the valley, since this is the level at which the spillway of a new dam must join up with the diversion channel. The diversion channel as it approaches the new site from the creek, is thus above this top water level and only needs to be opened to allow the water to flow in.

F. Relationship of creek and channel falls

The feature which permits the use of the flows from a creek, is a suitable relationship between the fall of the creek and that of a diversion channel. Contour-wise on a map of the land, the contours, after crossing over the creek, would first hug the creek course and then swing outward and further from the creek as they progressed.

In other circumstances the fall of the creek may be too flat and the contours of the land remain too close in along the creek for this scheme to operate. A large storage site is again sought near the creek’s entrance to the farm and from which the water may be pumped to a channel from which one or more higher storages may be filled in a similar manner, as with the gravitational set-up. Then a pump of suitable capacity may be set up permanently to lift the water from 3 through 15 metres (10 to 50 feet) higher according to the slope of the land.

For instance, if the average slope of the land, main ridge to creek, was 1 in 20 then a pump lift of 12 metres (40 feet) would permit the gravity irrigating of a strip of land more than 120 metres (400 feet) wide. This is after allowing a 6 metres (20 feet) height loss for the pump-filled dam to release the water through its lock-pipe system. If, on the other hand, the storage requirements were satisfied in a dam 3 metres (10 feet) deep, a strip of irrigation land 180 metres (600 feet) wide would be provided.

In yet other circumstances the size of the creek storage may be much larger and of maximum capacity compared to creek flows; then the full irrigation potential of the situation may be satisfied by pumping into a channel for direct irrigation. Very large volume pumping is now quite practical and economical in such circumstances.

G. Diversion channels lines for property planning

Whenever it becomes necessary to decide how best to control and use farm water channels for water diversion and for irrigation are involved. The lines of these channels are the lines which most influence the planned development of all the land in their water systems.

Thus far, only the water catchment relationships in one half of a land water section has been considered; that is the one side of a main ridge, with its primary valleys and primary ridges, down to and including the water course below it. When the examination is widened to the complete land-water section which embraces all the land lying between two creeks, including the creeks themselves down to their junction, new water catchments and relationships intrude with wide opportunities for profitable water deployments.

It may be that two creeks, which both carry water after rains, enter the land. The height relationships of them at their entry points to the property may indicate various possible water transfers. The general fall of the creeks and the land, may allow the gravity transfer of some of the water from one creek catchment to a storage on or near the other, to increase a supply to more economically useable quantities. Or, all the land most suitable for water applications may be associated with the creek or the catchment with the smaller supply. More examination than was entailed in the first example will probably be necessary.

Surely on this and other occasions of still wider scope, a good contour map is of outstanding value.

With the aid of a good contour map, and the knowledge a farmer has of his land, the various contours could first be considered as if every contour line was instead, a line which had the rate and direction of fall that might be required for water transfer. Then by following selected contours from the creek through to the other one and in reverse, all the possibilities of the situation would gradually unfold themselves and what surprises and absorbing interest this occupation generally creates!

A completely unsuspected relationship of water and land soon appears and often one item only may, when developed economically, add more to the value of the area than the property's original purchase price.

Of course the contour lines on a map are not the falling lines of channels for water transportation, but, because the rates of fall for all types of channels, including those of the natural creeks and stream courses, logically tend to become less and less as the country being considered is flatter and the vertical tolerances dwindles. The examination of the contour map for these discovery purposes is a very practical approach.

For instance, the general fall of channels in undulating country may be 1 in 300, but if this rate of fall were to write-off an undertaking because too much vertical height were lost, it would be an obvious step to lessen this fall to 1 in 400 or to 1 in 600 to gain the critical height. But on flatter land there may be no such rate of full fall as 1 in 600, because the fall of the country itself may be only 1 in 1,000 or 1 in 3,000, so an appropriate rate of fall for a channel has to be less than that of the country; and all these various considerations are soon obvious from a good contour map.

When it comes to the disclosure of suitable water storage sites on the larger properties of more gently undulating land, a contour map may reveal outstandingly valuable locations which an owner has not noticed in decades of property management. If the chief asset of land is water, surely the property owner must endeavour to control its flow for his property.

H. New look at farm water resources

While it is not possible to describe in the course of one volume all of the even more commonly met water resource development opportunities, there does emerge from this brief recital a few fundamental, practical guides and common sense principles which will apply for widely differing circumstances. As a simple start, the farmer's own land should be looked at anew. Now is the time to discard the older, false notions and illusions about soil and water that are rooted in the conservationist dogma.

Throughout the whole of this continent, water flowing off the farms and the grazing lands should be looked at firstly as assets not staying where it rightly belongs. Then the landsman, examining his waters afresh, should realise that his most valuable potential is the water resource and will provide, by its own development and use, the first basic details and lines for the planned development of his whole property and for the recreation of its landscape.

It is certainly obvious enough that water flowing to the farm from a catchment larger than the farm itself, should be considered in the first appraisal of farm water resources. Particularly so since it may not only supply the first permanent development lines, but it may dominate the whole improvement and working program.

The first place to seek for the control of this flow-in water must surely be at or near the point of its entry to the property. And if it is not practical to do so there, control points are then sought elsewhere by following the stream course downwards. The higher up on the landscape that water can be made available, the more valuable is the water and greater is the area of land which lies below it and on which it may be used.

For farm run off itself, (Category 2 in the Keyline scale), the Keylines of the primary valleys, mark the water line of the highest possible water storage dam sites in the valleys and these should receive due consideration. While on occasions one dam site may be so outstanding in its advantages as to dominate the whole course of development, it would be only rarely that the great advantages in efficiency of the inter-connected system of dams should be broken to take advantage of a more favourable site for one of them. Moreover, there is usually a measure of adjustment possible which can be exercised in favour of both the dam site and for keeping it in the chain of dams.

There are occasions where a landholding has only one primary valley suitable for building dams, the other valleys, if any, having no shapes of any such significance. Two or more dams may then be constructed in this one valley in stepped fashion one above the other. In this instance diversion channels would be used to bring in the water to each dam from the area which could best supply it, or even from both directions if necessary. The overflow from the topmost dam may be directed to the next lower one and so on throughout the series. This valley, with its own dams and their channels, then supplies the planning lines for the whole property because of its predominating water influence. But putting in dams in this stepped fashion in this particular valley and employing an inter-connected series of dams in another set of circumstances, does not make the two schemes competitive. It is simply that water overflowing from a higher to the next lower dam of a series of stepped dams, loses height of from 3 through 15 metres (10 to 50 feet) at each overflow. This is acceptable in design only where it is unavoidable and especially so, when compared with the loss of height in the overflow between dams in the chain series of about a metre or less (10 to 50 inches). But there is a place somewhere for every useful scheme and idea to serve its purpose in the development of the water resources of the farm and grazing lands.

This chapter has stressed the need for the proper assessment of the water resources of each individual farm and grazing landscape. The most practical and worthwhile method for the farmer and grazier to solve the problem of water resources assessment, lies in the methods of planning outlined in this and in other chapters of this book.

XII. FARM DAMS - DESIGN BASICS

The purpose of providing a discussion on the design of dams for relatively small area water storage, is that there is a serious need of it for the farmer and grazier for others who work with them on the land. It is important that a man who is anxious to do the best with what he has in the way of land and its water association, can be able to think practically on the matter of farm dams and not have a seemingly insurmountable blind spot which may prevent him thinking constructively about improving his land.

A. Farm Dams For Stock Water.

The usual one-in-every-paddock stock dam is small and too shallow. Without an outlet to draw off the bottom water it has no means of keeping the water good. Stock not only drink this water, they stir up mud, urinate and dung in or around it and are then forced to drink water which increasingly becomes a polluted pool.

Deposits from stock is not the only source of pollution. Leaves and dry grass get trapped in the water and the process of vegetative decay extract oxygen and make the water sour.

Then when the pool overflows with rainfall, little of the pollution which settled towards the bottom, is disturbed sufficiently to flow out with the overflow. Even when the dam is filled, the polluted accumulations are still below the better quality top water. Usually the water the stock drink is the shallow water near the edges and here they stir up the mud. As the water is used the polluted water becomes exposed and the stock are compelled to drink water of declining quality often as a dry spell or drought develops.

During droughts, great numbers of stock die through drinking bad water. While good water and poor quality dry grass will keep stock alive for a long time, dead and dying stock have been found in many paddocks still containing dry feed, but very bad water. Some of these dams were found still in use with the decomposing carcases of stock in the water.

Droughts have proved that the usual Australian stock dam is a mistake, even a catastrophe, which costs farmers and graziers millions of dollars.

It is not only at the point of water pollution, which is allied with poor quality feed or feed shortages, that stock die and farmers lose money, but at the unknown level of water pollution which prevents stock from getting the best from the food they eat. Yeomans discussed the matter of stock water with Dr. W. A. Albrecht, Professor of Soils, Colombia University, Missouri,

U. S. A. He had experiments showing that good cool spring water in a shaded location was worth about a quarter of a kilogram (half a pound) of extra beef per day per beast in comparison with ordinary stock water.

No storage, no matter how big, will keep water fresh unless water is continually drawn off from the deeper levels. This holds good for the largest natural fresh water lakes of the world, the man-made giant storages, the farm dams of all sizes down to the smallest iron tank with its house roof catchment. Fresh water will not stay fresh. It must be continually drawn off from the storage bottom. In the farm stock dam a pipe and valve fitted to the bottom is the answer.

The smaller the storage the shorter its life in supplying good water unless it has an outlet from the bottom. In areas where salt accumulates, the story is worse. Nevertheless, we have constructed farm irrigation dams on streams too salty for stock to drink. The outlet by-passes the normal salt flow and run-off from heavy rain fills the dam with fresh water for irrigation.

A large irrigation dam can be successfully used for direct stock watering, as there is no danger of damage provided the length of time it is in continuous use is kept to proper limits. The larger the dam, the better the surface water and the less fouling.

1. Stock tanks in relatively flat country.

The stock tank in relatively flat country poses a special problem. Subject to extremes of pollution, the water is usually contained within the excavation which forms it and therefore a Lockpipe system would be ineffective. A total redesign of flat country stock water storage is necessary.

The first stage of improvement is in site selection. Whereas sites are now usually in the flattest of flat land where run-off cannot be stored above ground level, the new sites should be in areas where the land has its most shape. Land termed flat does have primary valley and ridge shapes although these may be hardly noticeable. The requirement of site and dam is simply that some of the water must be stored when the dam is full against the wall as well as in the excavated hole. The contour dam of Keyline, located on the steeper part of a flat ridge, may be the answer. Then a Lockpipe at ground level through this wall can flow when the dam is filled or overflowing. On the inside, the pipe would bend down to the bottom of the deep water so that the foul water would be sucked up and flow out of the lock pipe.

A better solution would be the use of one larger dam to serve troughs in three or more adjacent paddocks. When not in use the troughs could be turned off. Evaporation would be greatly reduced in comparison with smaller stock dams in paddocks.

A turn of the Lockpipe valve when run-off flows into the dam releases the bad water to hold the good, but what can be done for existing small stock dams?

2. Better quality water from existing stock dams

In the case of an existing stock dam a great improvement in the quality of the stored water can be achieved by positioning a 100 mm (4 inch) diameter PVC pipeline so that one end is in a slightly recessed position in the spillway and the other end is in the base of the dam. The inlet in the dam should be fitted with a cone strainer or at the very least an upturned 90 degree bend. This pipe will draw water from the bottom of the dam when the dam starts to overflow. Water will continue to flow out through the pipe while the spillway is flowing and as the overflow diminishes the last water to leave the dam will come from the bottom of the dam through this pipe.

This simple arrangement, to remove the stale water from the base of an existing dam, can be developed into a pseudo Lockpipe system, so that water can be drawn from the dam by gravity pressure at will. The pipeline needs to be extended from the spillway behind the dam to near the base of the valley and the outside tow of the wall. Here a valve needs to be fitted to the end of the pipe. An upturned elbow should also be fitted at this end to prevent an air bubble entering the pipe and collapsing the siphon.

A tee piece is positioned in the spillway a little down stream from the siphon’s high point. A valve should be positioned in the side branch of the tee. When the valve is open no siphoning action can occur and the pipeline can not lower the water level of the dam below the spillway. The bottom valve controls where the water is discharged; if closed, overflow water will first fill the pipeline from the bottom valve to the tee and then discharge in the spillway area; if open, water will be discharged at the end of the pipeline at the down stream toe of the wall. It is usually better to keep the bottom valve closed and the pipe full of water. Then the system can be used as a Lockpipe system. However the top valve must be closed before opening the bottom valve. When the bottom valve is opened the water trapped in the pipe is often enough of a prime to enable the siphon to start. The pocket of air in the pipe is sucked out by the rush of water though the pipe. Initially water can be bucketed into the pipe through the upturned elbow at the tee. In this case it is important that the slope of the top of the pipe will cause this water to flow to the outlet end of the system. A vacuum pump is another way to prime a large siphon.

The preferable means of keeping water reasonably good in smaller dams for stock, is by use of a lock-pipe through the wall and here the question of size arises. A 100 mm (four inch) line is about the minimum for effective water control. The next to be considered is a 150 mm (six inch) diameter lock-pipe. This is a critical size since it is the smallest Lockpipe which can provide reasonably effective irrigation on Keyline pattern for a small area. This size is much more efficient for the rapid removal of bad water and is also large enough to appreciably reduce the length of time the overflowing spillway of a dam flows and so protect the spillway area.

B. Farm Dams For Irrigation

The first purpose of the newer enlarged farm dams which these pages envisage remains basically the same as for present ones. They are for holding water when it is available but cannot be used, against the time when water is not available, but could be used. Once the great majority of farm dams were for stock watering purposes, although many more have been built for the dual purpose of irrigation and stock water since irrigating from dams on "Yobarnie" began in the 1940's. But since the relative requirements of water for growing all the feed a beast may eat to the quantity it will drink is approximately 300 to 1 the size ratio for the added purpose of irrigation is likewise very great. It will range from 40 or 50 to 1 up to as high as is practically and economically feasible.

Further comparisons:

(1) It is rarely envisaged in the provision of stock water facilities that all the water available will be required or needed since stock water is not the limiting factor in production, whereas irrigation water is for the express purpose of increasing production and therefore the volume available is the limiting factor in production.

(2) Stock water dams only rarely require all the available water from rainfall run-off, stream flow, and underground, so the site for them is by no means a critical matter in respect to these water resources. The most efficient site for irrigation dams for irrigation, demands a good relationship both to the land shape and other dams. This relationship is for controlling and using the water in order to increase profitability. The manner of these

things may dominate all development planning, and this has been seen already.

(3) Comparatively, the cost of the stock dam is not that significant. It usually ranges from below $1000 up to $5,000, although there are quite a few of them constructed in the dry and hot conditions which are much more costly. The controls alone for releasing the water from an irrigation dam will often equal and exceed the higher of these amounts and the earth-works cost additionally from $7,000 to $60,000 and on occasions even higher.

There is no widely accepted and used classification for the various type of water storage structures which will be employed for holding farm water where it belongs principally because, in relationship to their value and importance, the subject of them has been almost completely neglected. Professional engineers, with their sights set for only bigger projects have naturally overlooked them. Government engineers whose job it could be to concern themselves with research and experiments which would promote the maximum practical use of farm waters, had never been given the directive or the money by the Government to do either. They are usually not permitted to depart from the orthodox or even risk one failure which could at least provide some new and valuable knowledge.

There is still in this country the illogical division of authority in agricultural matters, which permits the Soil Conservation officer, on the one hand only to build a dam or construct a channel on a farm if it is a legitimate soil conserving measure, and on the other hand restricts a water supply engineer so that he may build a dam for water storage but not interconnect water storages through a series of properties or discharge the system into another valley. How could even the best planned farm development stand such nonsense?

A farm dam is a water holding structure consisting of an earth wall which is usually erected across a valley and which backs up the water onto the valley above the wall. A smaller portion of its water holding capacity may be held in a hole from which the earth of the wall, or part of it, was obtained. The bulk of its water storage is held up by the wall over the valley floor and extending up-stream according to the wall height and to the slope of the valley. The water of the dam can be released on to the land below with the aid of a pipe through the wall. This pipe is usually horizontal and at the same height as the bottom of the valley below the wall.

More favourable sites are characterised by:

(1) a flatter valley floor slope, which determines the distance the water will be backed up in the valley,

(2) the site for the wall being shorter than other sites in the same valley,

(3) the valley floor shapes being wider and flatter in cross section on the water side of the wall as against a narrow "pinched-in" valley shape, and

(4) a suitable location for a spillway or by-wash at the site.

Many stock water storages are simply excavated holes where the water is held below the level of all the immediately surrounding land. These, usually termed "tanks", are rarely made large enough to carry a sufficient supply for irrigation purposes. Such a tank, if dug for the storage of irrigation water, would be very costly since the ratio of water storage capacity to the earth moved is about 1 to 1, whereas this ratio for a dam will usually range from 5 or 6 to 1 and on many occasions better than 10 to 1. Of course on the flatter lands the water-earth ratio may be outstandingly favourable as for instance where a relatively inexpensive wall may back up water 500 or 1,000 metres (or feet) for each metre (or foot) of height of the wall.

Farm dams which are to store all the available water of a farm, do however permit of certain classification relating to their uses and to the shape of the land on which they are constructed.

1. Site Selection

The great importance of selecting the site for each farm dam will be apparent to the reader from what has been said before in the previous chapters. But it needs to be mentioned again. The site for any dam should be chosen on the basis that the dam can become a part of a total farm water development scheme. The site should not be thought of as something apart, but as a part of something of much greater import than the construction of a single dam. Even the availability of an outstanding site for a dam should not change the obvious form which the control of the water resources should take. It must not be allowed to restrict the profitable possibilities of the whole plan.

Therefore, the first basis of site selection must rest on the examination and understanding of the complete land-water section in which it lies.

The highest place for any dam, in any primary valley, is where the top storage level of the dam is on the Keyline contour. Any outstanding site in the valley must be below this point; otherwise it would be used automatically on its own or as a part of the highest inter-connected chain of dams. If it lies below the Keyline of a primary valley but too high to be included in a contemplated lower series of dams, it can be located by constructing the dam independently. In this case for filling the dam, a water gate, set in the higher diversion channel could remain open at appropriate times. If there is no such channel an independent channel for the special dam could be constructed and rise from the top water line of the dam in the valley into the rising country.

There is invariably more land above to shed water to a channel which rises into the rise of the country, than there would be if a channel were constructed to rise into the fall of the country.

All farm dams that are constructed in primary and secondary valleys have design and constructional features similar to those of the dam described in an earlier chapter. These dams will differ widely in their capacities even with similar wall sizes and heights. The big factor in the difference is being the important one; the slope of the floor of the valley at the site of each dam. For instance, assuming a constant wall length of 120 metres (400 feet) and a constant water depth of 6 metres (20 feet) above the pipe, a dam with a valley floor slope of 1 in 15 would have a length from the wall to the water line in the valley bottom upstream of 90 metres (300 feet); with a valley floor slope of 1 in 30 the length of the dam would be 180 metres (600 feet), and with a valley floor slope of 1 in 100 the length would be 600 metres (2,000 feet). Storage capacities could be 19 ML., (23 acre feet); 38 ML (47 acre feet) and 126 ML (156 acre feet) respectively.

a) Minimum shape for a farm dam

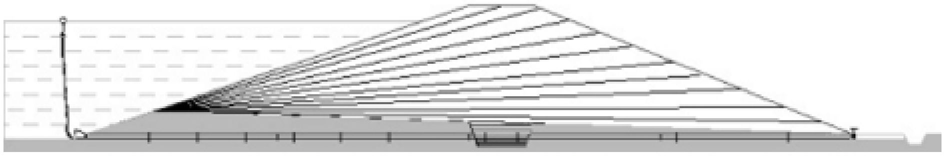
A dam in a primary valley may be considered to have a minimum shape if it’s length, being the distance the water is backed up from the wall to the furthest water line, is equal to the length of the wall. In the above example, wall length of 120 metres (400 feet) in a valley of 1 in 15 slope, makes the length of dam only 90 metres (300 feet), so such a dam is not of minimum shape and would not be further considered. The other two examples would be considered to be of satisfactory shape but not if other sites were even more favourable.

The highest possible sites for valley dams are those which have their top water line coinciding with the Keylines of the primary valleys. At these places are found the widest ranges of choice, where many positions at the

Keylines are completely unsuitable for dams, while another valley's Keyline site may be very good. Lower down in the same primary valleys the suitability of possible sites for dams do not vary nearly so much. The particular site chosen, where a chain or series of dams in these middle or lower positions is to be used, will be most often suitably indicated by the diversion channel and by the depth selected for the dam.

b) Depths of farm dams

The depths of farm dams and the height of the walls, are determined individually for each site. The principal considerations are (l) the slope of the valley floor and (2) the water capacity of the site. Provided there is ample water available from the natural catchment, or which can be brought in by diverting it from outside, the dam should be as large as possible and be near the maximum economical wall height. Walls over 10 metres (33 feet) high should be individually designed on the more orthodox engineering lines.



Cross section of a Keyline dam with 8m (24' 3") high bank.

A good safe maximum for a farm dam in medium undulating country is a 7 metres (23 feet) dam with a 8 metres (26' 3") wall. Of course some sites may warrant higher and larger walls but even so, it is advisable to first check the site by pegging for this size dam. If a dam 7 metres (23 feet) deep is considered to be a good working maximum, then 3 metres (10 feet) deep is similarly a good working minimum and the large majority of farm dams for irrigation would fall in this range.

Consideration of pipe lengths has some bearing on this. An 8 metre wall with a 4 m crest and 1 in 2.5 batters inside and out will need 44 metres of piping to get through the wall. Altering the inside batter to 1 in 3, which is sometimes a licensing requirement, alters the pipe length to 48 metres. Pipe 300 mm (12 inch) in diameter usually comes in 12 metre lengths and larger diameters often come in 6 metre lengths. The steeper batter of 1 in 2.5 on the inside leaves 4 metres of pipe, if 4 lengths of pipe each 12 metres long are purchased. This spare pipe can be effectively used to get the irrigation water under the road, which is normally positioned parallel to the irrigation channel, if the road is to cross the valley at the base of the wall.

From what has been said in reference to the valley floor slope of the site for a proposed dam, it will be appreciated that as the land considered becomes flatter, the water storage requirements tend to be satisfied with lesser wall heights. Also the flatter valleys tend to become wider and so the walls for dams in them will be longer. Therefore a 8 metre (26 foot) wall becomes an increasingly larger undertaking. In these cases the first checking of a proposed flatter site could be made, by pegging it as for a dam 3 metres (10 feet) deep or a wall height of ~4 metres (13 feet), and by increasing the size if this proves smaller than the requirements.

c) Flat Country Dams

On land which is generally considered to be flat and dry, the primary valley shapes of Keyline still persist but may not be obvious to the eye. On such land, the flat primary valleys in flat surroundings can often be used for the temporary storage of heavy rainfall run-off. The walls for such storages need be little more than long low barrages up to only 2 metres (6 feet) high. The water would be used as soon as profitable on a paddock which has been fenced and specially prepared for it then released from the storage quickly by a large Lockpipe or, in some circumstances, by water-gates. Such a water storage may provide water for irrigating only three times before the water is all gone, but it could still be a most profitable undertaking. In the bottom of the dam a deeper and smaller excavation could remain as a stock watering point.

2. Farm Dams in a Creek

The various valley dams are generally simple construction jobs, but the damming of creeks involves a wider range of site conditions. The damming of some creeks would be beyond either the capacities or economics of most farmers.

While on many occasions some of these streams which have very large catchment areas can be controlled and have water diverted from them for farm use, the smaller creeks are likely to be more suitable for these purposes.

Since a water license is necessary for creek dams, it is as well in the first instance, to discuss the site possibilities of a proposed creek dam with the local officers of the Government water authority.

The basis of the design and construction details for a creek dam involve:

1. The selection of a spillway area that will permit the overflow water leaving the dam and returning to the creek lower

down, without damage to the immediately adjacent land;

2. Provision for the control of water which may be flowing in the creek during the construction of the wall;
3. Determining the preparation that is necessary for the wall site. The pegging of the site itself is done as with a valley dam.

Selecting the site for the lock-pipe is also more critical than for a valley dam. Preferably it should be located by excavating the lock-pipe trench away to one side of the flowing water with the level of the bottom of the trench a little lower than the creek. The trench should be kept isolated from the flowing water until the lock-pipe is placed and properly covered up, when the flow of the creek is turned into it. This will require the cut-off trench to be done in two stages also. Firstly, the section under the Lockpipe trench and secondly, the section of cut-off trench under the creek. It may be possible to divert the creek flow around the site in a channel. Once the flow is controlled, the preparation for the wall site is done the same as for the valley dam.

The selection of the excavation areas to provide the earth for the wall of creek dams is a little more critical than for valley dams. If this material can be obtained from near the wall and below the water line of the finished dam, so much the better, but frequently it must be procured elsewhere. Generally the wall of a good dam site on a creek, is associated with the end of a longer primary ridge on one or both sides of it. The spillway may be cut out of the end of one of these ridges. The same ridge could supply all the earth for the wall as well.

In the construction of the wall itself, extra care should be taken to protect the main bulk of the wall from possible flood damage, so throughout the work, the wall is made to slope along its length from the side of the creek with the steeper bank down toward the flatter side of the site. Flood overflow would then occur further away from the main section of the rising wall. With the lock-pipe open and free during construction, the maximum protection is then assured.

Frequently water will have to be pumped from a large creek storage, therefore a site for the pump and its suction line should be prepared as part of the construction work. This should ensure that all or most of the stored water can be pumped from the dam and the one permanent set-up of the pump, without having to move a pump down to contact the falling water level.

3. Non-valley Dams

In some circumstances where valuable water flows to waste, there may be no valley or creek site for a dam. There are two designs which may apply and which will provide dams of economical cost.

Firstly; 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 main wall. Wing-walls close off the ends of the contour section of wall. The two wing walls taper up the slope from each end of the contour section of wall to points both at and above the water level of the dam.

In the flat lands all design features of dams are flatter: The dams themselves are shallower, water diversion and irrigation channels flatter, but the irrigation channels are built up so that the water flows above the level of the land. The land to be used for irrigation is also flatter and all the flat land methods of irrigation, can be used from the supply that is held in contour dams.

The critical design feature of this type of dam, other than the all important one of climate and its associated run-off, is 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 around a flat ridge shape, the dam being on the inside of the curved shape. 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.

A contour dam should be located as high on the property as is convenient. There must be run-off and sufficient catchment area above the water diversion channel to fill the dam. As to size, it may range from around 22 ML (five million gallons) to 114 ML (twentyfive million gallons) or more. To bring the matter to a practical consideration, we may assume a contour dam is to be designed with a capacity of 100 ML (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 to be 3.6 metres (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 of about 275 metres (900 feet) long. Water 3.6 metres (12 feet) deep on a 1 in 50 slope would place the water line up this slope 3.6 multiplied by 50, or 180 metres (12 feet x 50 = 600 feet), the dam thus having an area of 5 hectares (a little over 12 acres). The average depth of a contour dam is somewhat over 50% of its full depth, or about 2 metres (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 0.9 metres (three feet) but the circumstances of design in a contour dam suggest that this figure be reduced to 0.6 metres (two feet) or a little less. 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 as serious as in the valley dam. Moreover, the inflow of water to the dam is readily controllable.

a) Contour Barrage Dams.

The facts mentioned in the preceding paragraph suggest that the minimum or cheapest construction methods may be used in building the wall, also that, with the lower wall height the batters may be steeper. The wall height will then be 3.6 metres (12 feet). Comprising the depth of water 3 metres (10 feet) plus 0.6 metres (two feet) of freeboard. As minimum construction methods can be employed, no allowance for settlement and shrinkage is made.

The cross section of the wall is as shown in Figure 16 and the plan of the dam in Figure 17.

With the constructed height 3.6 metres (12 feet), the width of wall shape at the base is 18 metres (60 feet), with batters 1 in 2 with a crest width of 3.6 metres (12 feet). The lock-pipe can be 18 metres long and 600 mm in diameter. It is placed into solid ground with the top of the pipe being level with the natural surface at the outside toe of the wall.

There will be approximately 0.35 m (1.2 feet) of solid earth above the top of the lock-pipe level on the inside of the wall. At distances of 25 and 30 metres (80 and 100 feet) from the inside toe of the wall, there will be 1.7 and 1.8 metres (5.6 and 6 feet) of earth respectively above the level of the top of the pipe and more than sufficient for the wall without digging earth below the inlet level of the lock-pipe.

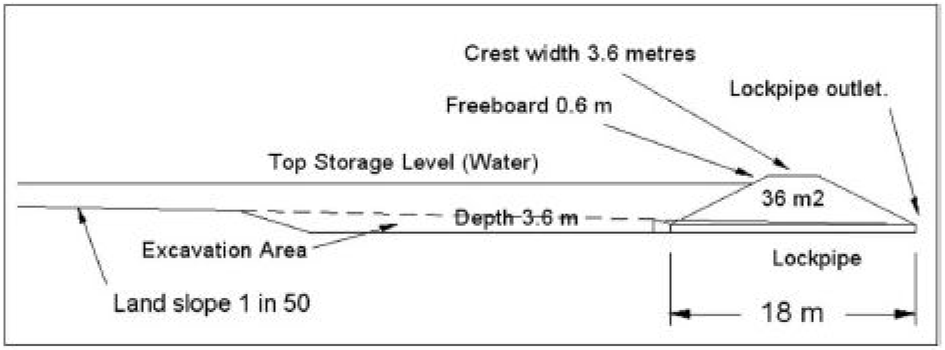


Figure 16 Cross section of excavation area and wall with 1 in 2 batters. Wall is 3.6 metres high. Cross section of excavation area matches the wall cross section, excavation below the pipe is unnecessary.

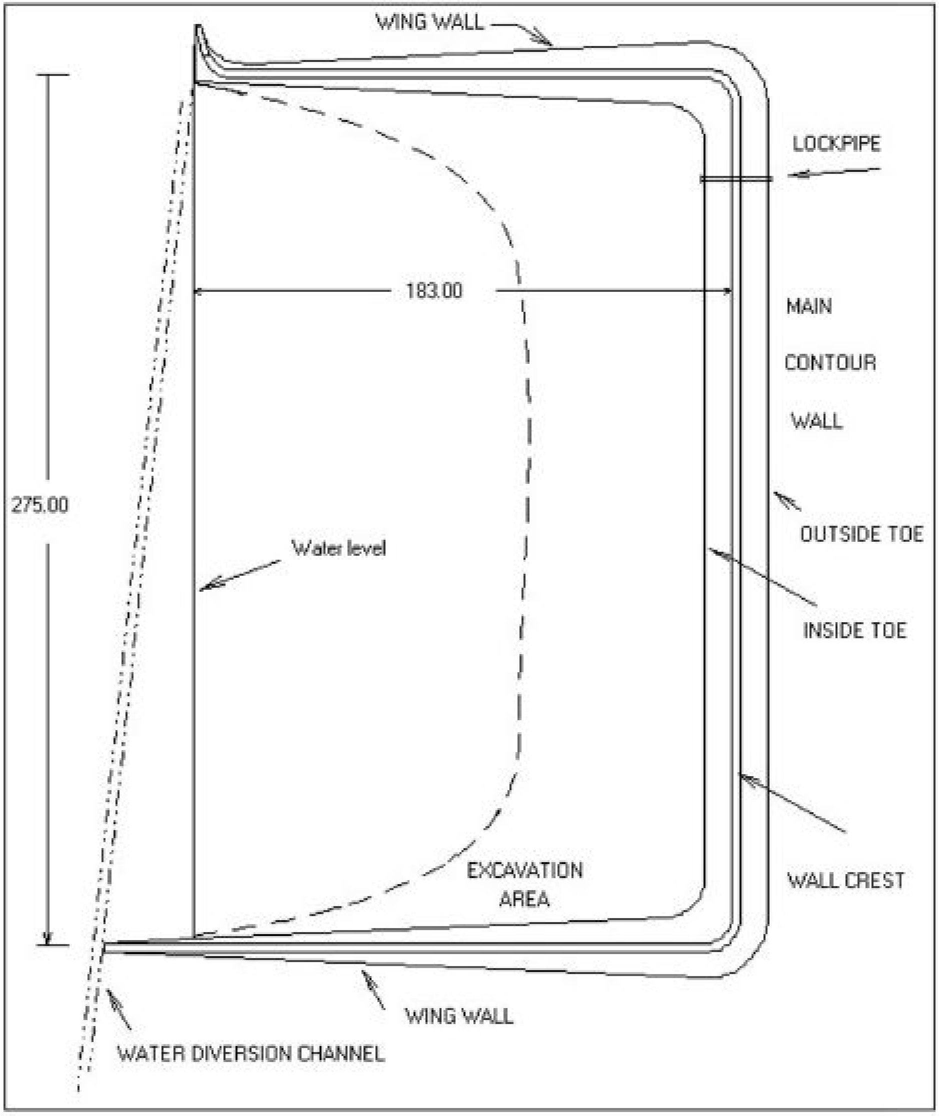


Figure 17 Plan of contour dam showing wall, water diversion channel excavation area and wing wall.

The water diversion channel for a contour dam, like those for all dams, does not fall directly into the dam, but is constructed right along and above it, reaching water level height at or near the spillway end of the wall. The channel may be much flatter than the fall generally employed for the valley dams. A flatter channel has less capacity, so that it needs to be of larger section. The channel should fall in the down-land direction.

The position of the lock-pipe 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 slope immediately below the dam is to be irrigated, the lock-pipe is placed in the main wall at the end where the diversion channel first reaches the dam. In other circumstances it will be placed in the opposite end.

The price per cubic unit of earth moved in a contour dam of this lesser 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 as against a wall 7 metres (23 feet) high.

Marking-out and site preparation should proceed as for a valley dam, with the clear marking-in of the wall shape on the ground with a furrow line. The dams top water line should also be marked. That part of the water diversion channel which is along the top of the dam could be constructed first to prevent any run-off into the area during construction.

A cut-off trench for the full length of the main wall and the two wing walls, should be used, but may only need to be about 0.1 m (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 it’s supervision. The area of the wall site is chiselled along the line of the walls to assist bonding as before.

A contour dam of this style provides a water-earth ratio of approximately 4.1 to 1 and the same general structure on land sloping 1 in 100 would improve on this ratio to 8.4 to 1. Having regard also to the low cost of earth moving for a wall of this modest height, the structure is a very economical one for farm water storage.

b) A ring dam

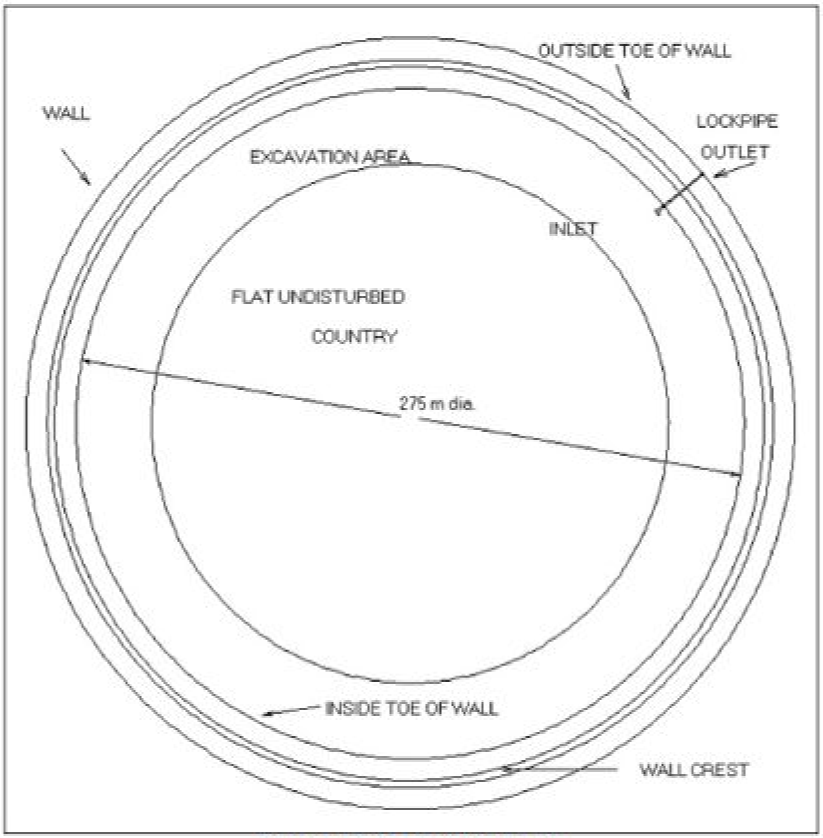


Figure 18 Plan of ring dam.

Figure 19 Section of ring dam.

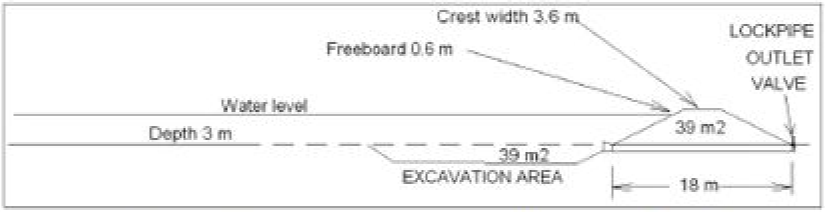


Figure 20 Cross section of excavation area and wall.

Where the slopes are so flat that the contour dam becomes unsuitable, there is no way to store water above ground level other than with a closed wall dam and by pump filling. The most usual source of water supply is a stream, which may flow only after heavy rainfall and these facts should be noted when locating and designing the dam with its related filling structures. In some circumstances, though a dam must be filled from a certain water-course, it may be a disadvantage or even an impossible hazard, to construct the dam close to the water-course. 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 portion of the bank of a watercourse.

There is a general idea that water has to be pumped over the top of the wall of such a dam. However the ring dam may be filled also by pumping through the lock-pipe when this is suitable. The water from a ring dam can be used for many different irrigation systems varying from flood to any type of spray irrigation.

The construction of the ring or other closed-wall dam, follows the general procedures already given. The size of the lock-pipe may be increased according to the capacity of the pump which is to fill the dam, but generally a size of 400 mm (16 inches) is suitable, unless it is to be used for Keyline Flood-flow irrigation in which case a 600 mm (24 inch) pipe is preferred.

The importance of making proper arrangements for the filling of ring dams, or any closed-wall dam, cannot be over-stressed. The full layout should be decided and included in the design of the dam itself. A creek weir diverting flow to a channel and bay, from which the water is to be pumped, should all be built and completed as part of the dam construction. 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.

Plate 22 Rectangular irrigation dam filled in 10 days by pumping from an adjacent creek and bore. One irrigation, if done when this dam is full, leaves sufficient water for the introduced marron (shell fish) to survive and breed. Photo taken from front veranda of home. Aspect is "North-to-Water". Best aspect for the Southern Hemisphere.

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, 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. The most suitable dam filling arrangement is a permanently located pump and engine that can be operated under the worst weather conditions. A large low-head highcapacity centrifugal pump, selected to exactly suit the requirement, or an axial flow pump may be used. A lower initial cost method is to arrange a permanent pump set-up so that the power of a farm tractor can 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 immediate operation.

Plate 23 Panorama continuing from right side of plate 22. Flood-flow contour channel can be glimpsed wrapping around the dam in both photos. When full, the channel inundates back to the wall. Steering banks can be seen beyond the channel.

4. Parts of a Farm Dam

The two principal parts of a farm dam are an "earth wall" which holds the water back over the "pond area". The features of the earth wall are its "crest" or roadway on the top of it, which is wide enough for easy maintenance and for equipment vehicles to pass over it; its inside (water side) and outside "batters" or sloping sides where the degree of the slopes is described as for instance 1 in 2, which means a fall of 1 unit (foot, cm., metre) vertically for 2 units (foot, cm., metre) horizontally; its "spillway" overflow or by-wash which carries away the excess water flowing to it after it is filled; its "freeboard", which is the minimum height of the wall above the bottom level of the spillway and may be regarded as the safety margin of the dam when filled. The "foundation area" of the wall is the contact of the wall with the solid earth of the land below it. A pipeline, laid during the construction of the wall, releases the water from the dam through the base of the wall in the valley.

The "pond area" of the dam is enclosed by the line of the top water level which coincides with a true contour having its starting' point at the level of the spillway.

a) Constructional Features For A Farm Dam

It has been stated that a point had been reached where, during the course of pegging the line for a diversion channel, a longer peg had been placed on each side of a primary valley. The line of the two pegs was said to represent both the centre of the earth wall of a dam and the height of the top water level of it. Before a dam can be constructed, both the design for the dam and the proposed site for the dam, must have constructional practicability. The design is suitable if it can be built with the equipment and material available on hand for the construction of the wall.

The lowest costing dam is only possible if the foundation area is satisfactory and, if all the material which is to go into the wall is available, either within the pond area of the planned dam, or from the land above either one or both ends of the wall site.

Assuming that the water line contour is already pegged and the centre line of the wall is fixed by the two longer pegs referred, the pegging or marking out of the site proceeds by first placing a few pegs to outline the area of the wall's contact with the land of the site. On the inside of the wall this is the "cut and fill" line. On the outside of the wall this line of pegs reveals the outside toe of the wall. The area between these two lines is called the foundation area of the wall. This foundation is examined as to its suitability by digging test holes into it at several points by hand or machine with an earth auger, posthole digger, back hoe or excavator. The first holes can be 1.2 to 1.5 metres (4–5 feet) deep but if the material is satisfactory in the central area of the valley and from one or two holes on the sides of it, other holes need only penetrate through the soil far enough to disclose the same material.

It is always worth finding out something of the local experiences in dam building if this is the first dam for the property. If even the smallest of dams hold water satisfactorily against their walls and above the level of the land, it is quite reasonable to assume that the much larger ones to be built of similar material will also function satisfactorily. This local information in respect to the suitability of the earth available for dam building, can be added to by consulting with district water authority officers.

With the determination of the suitability of the wall's foundation area the complete pegging of the site may proceed. In these following pages, reference will be made to the plans in Figure 21 and Figure 22 on the next page.

The plan for a dam will show the detailed measurements of the wall. The height of a dam wall is the vertical measurement between the outside toe of the wall, in the centre of the valley, and the crest of the wall. This includes a 1.0 m (three-feet four inch) freeboard. (the vertical distance between the spillway level and the crest of the wall. A freeboard of 900 mm (three feet) is suitable as a general rule except in cases where the width of the spillway is made less than it should be owing to site characteristics, in which case the freeboard would need to be increased. With the conversion to the metric system of measurement in Australia, the freeboard allowance has generally been increased to one metre for design convenience. A conservative maximum wall height for a farm dam is 8 metres (26 feet).

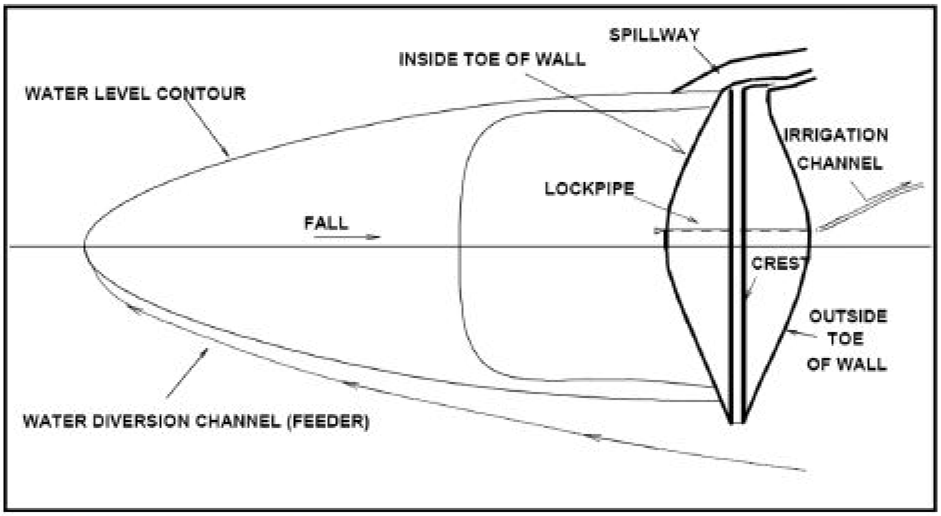


Figure 21 Plan of farm dam.

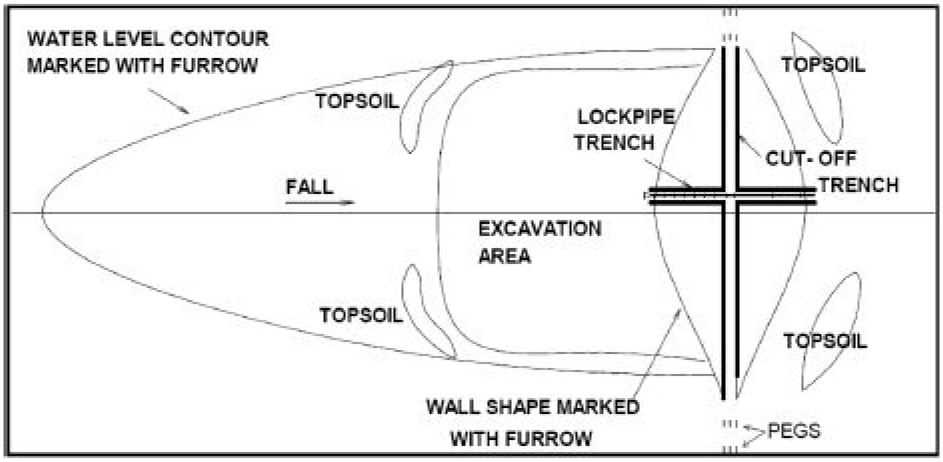


Figure 22 Plan depicting marking out and site preparations.

b) Spillway

The spillway of a dam, like all other features of good farm irrigation dam construction, has to be correct for the dam to be a good one. Usually the construction of the spillway will produce a surplus of earth which is then used in the building of that end of the wall.

The batter between the end of the wall of the dam and the bottom level of the spillway should be about 1 in 3 or flatter 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 3 falling from the end of the wall of the dam, 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 that, on the completion of the dam and its subsequent settlement, there will be 0.9 metres (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 0.3 metres (one foot) of water across its full width and when this happens, there would still be a further freeboard of 0.6 metres (two feet) to compensate as a safety measure for bigger floods.

Larger spillways are necessary for farm dams built in the lower parts of large primary valleys and for creek dams, since they usually have considerably more catchment area than a dam that is higher in a valley.

To secure the necessary width of spillway with a dead flat floor, considerable material may have to be excavated into the rising land 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 material excavated from the spillway.

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 because it would need to be refilled with loose earth that would not be as stable as undisturbed material.

The width of a spillway will depend on the catchment area of the dam and on the likely intensity of storm rainfall. If this information is not available, the following may serve as a guide:

(1) Simple Spillway formula. - Imperial

Take the square root of a figure which represents four times the maximum catchment area of the dam in acres and call the answer the width of the spillway in feet. Therefore if the catchment area of a dam is 25 acres, four times 25 equals 100 of which the square root is 10. The spillway width would be 10 feet (3.05 metres). As a second example, if the catchment area of a dam is 400 acres, the formula will indicate a spillway 40 feet wide. The square root of 1600 is 40. (Forty feet is 12.2 metres.)

The preceding Imperial measurement spillway formula is not as tidy when exactly converted into metric. Conversion is achieved by using hectares (not acres) and by reducing the multiplier factor from 4 to 0.917 in which case the same result is achieved. However for the sake of simplicity round up the 0.917 to 1. The result is as follows.

(2) Simple Spillway formula. - Metric

The width of the spillway in metres is the square root of the catchment area in hectares. Thus if we use the same areas 10 hectares (25 acres), we get 10^0.5 = 3.2 metres. For a catchment area of 162 ha (400 acres) we get 162^0.5= 12.7 metres, which is just a little wider but certainly close enough to the original formula.

The 12.7 metres spillway width can be deduced using the rational formula using a time of concentration of 6 hours; a rainfall intensity of 25 mm per hour and a run off coefficient of 65%. This simple formula is intended for areas of medium intensity storm events, which in this case is 150 mm (6”) in 6 hours, i.e 243 ML total rain volume. If at all possible confirm spillway width provisions with experienced departmental officers.

The lockpipe acts as an additional safety factor if opened up when a dam overflows.

The crest width of the wall, apart from being wide enough for practical farm purposes, also needs to be wide enough to accommodate the construction equipment. A minimum width of 3 metres (10 feet) suffices, but if the crest is to be used frequently as a roadway, a more suitable width would be from 4 to 5 metres (13 to 16 feet). Increased width will add to the cost of earth moving. The batter slopes and the height of the wall and width of crest determine the width of the base of the wall.

c) Batter Slopes

Different slopes for the inside and outside batters are frequently recommended since this is the case with the "big" dam, but in 25 years of experience in the design and construction of these dams, we have found that there is little for and much against this practice. The one slope for both batters is much more practical for these dams, which after all are very modest structures as compared with the "book" dams which are for Government and large community service. If the farm dam were to be built strictly as the scaled down model imitation of the "big" earth dam which is 1,000 and more times larger in the wall, and as is much too frequently a standard recommendation, its cost would be unnecessarily high.

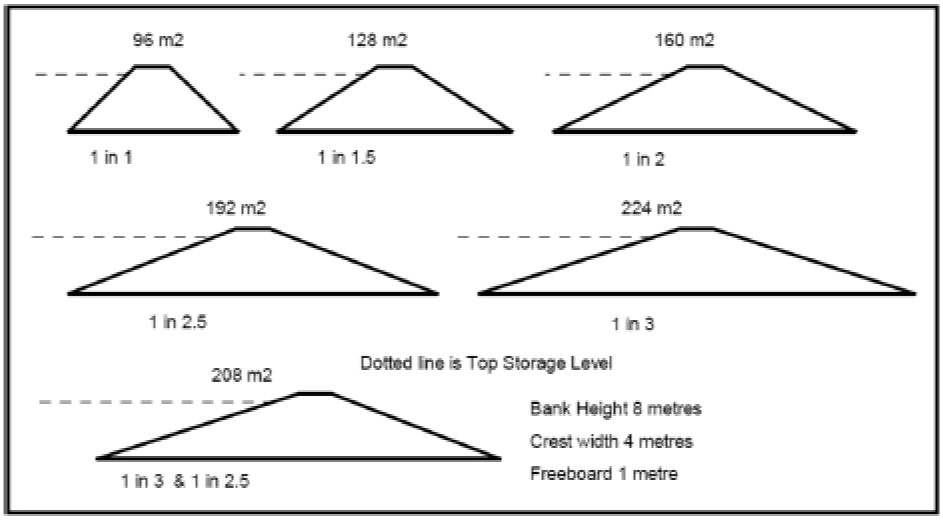


Figure 23 Cross sectional areas of dam walls showing various batter slopes.

(1) Batters Affect Cross Sectional Areas.

Many farm dams have been constructed, and served their full purpose, with a batter as steep as a bulldozer could negotiate on the inside and the outside batter as steep as the angle of rest of the earth, which was merely spilled over from the wall as it was built. Although most of such dams do hold up, this type of structure is not favoured because:

1. the rate of failure may be higher;
2. the crest cannot be satisfactorily formed and would be unsuited to the passage of farm equipment;
3. follow-up service or reconstruction would be difficult and more costly; and
4. the wall would be unsightly since the outside batter is too steep to grow grass successfully.

We have designed many good dams with 1 in 2 batters, but batters of 1 in 2.5 are a little easier to maintain and grass over. In this instance 1 in 2.5 batters are assumed, so the toe of the batters would protrude from each side of the crest two and a half times the height of the wall, which measures 20 metres (66 feet). Therefore with a crest width assumed of 4 metres (13 feet), the maximum width of the base of the wall in the centre of the valley would be 44 metres (144 feet), made up of twice 20 metres (66 feet) plus 4 metres (13 feet) width of crest. The pegging of the wall site can then be resumed.

The first pegs to be placed are for control. A peg is placed in line, on each side of the valley, with the two longer pegs which mark the centre of the wall and crest. These pegs are placed out of the way of the later workings to preserve the centre line and they should not be disturbed throughout the construction of the wall. During the earthmoving, a wall will tend to “wander” a little both up and down the valley, resulting in the moving of some of the earth twice therefore increasing the cost if control pegs are not maintained or if they are not kept in constant reference.

On either side of the centre-line control pegs, others are set to mark the line of each side of the crest. These last pegs are thus also well outside the working area and are preserved in position throughout the work.

Two permanent level-control pegs are necessary, one to preserve the level at which the spillway will “take-off” from the dam and the second preserving the level, as is determined now, for the top of the horizontal Lockpipe system. The Lockpipe is to be placed in position before the wall is formed over it. The level of the Lockpipe reference peg should correspond with the level of the valley centre at the point below the centre-line of the wall, or with the valley centre at the toe of the outside batter. If the latter is decided on then the height of the wall is also measured from this level. These two levels are not the same since the bottom of the valley, which will be below the wall, is sloping more or less downstream so the latter level is the lower one.

The two reference level points are transferred with the aid of a surveying instrument, to points at the same level on land, sufficiently far away from the working area so that they are not disturbed or lost. From these pegs now placed, every level and point location for the dam can be readily determined throughout the course of the work.

The pipe system mentioned is better not to be placed along the centre of the valley, although it takes its level from it. Instead, it is placed in an excavated trench a little off the line and parallel to the valley bottom and on the down-land side.

The inside toe of the wall when the excavation reaches full depth should be marked with several sighting pegs. This will indicate the inlet of the Lockpipe and the limit of digging near the wall at full depth.

Once pegging is completed and pipe systems are ready on site, site preparation and construction can start.

5. Wall Shrinkage and Settlement Allowances.

Shrinking and settlement of the wall needs to be provided for by adding 2% to its maximum height which equals 0.16 m say 0.15 m (6.25 inches, say six inches), making the total maximum height 8.15 metres (26 feet 6 inches). Shrinkage allowances do not have any effect on pegging of the foundation area of the wall. But, the outside batter should be built at 1 in 2.45 instead of 1 in 2.5 in the above example. The following diagram shows the upper part of the cross section of a wall 8 metres high with a 4 metre wide crest. The extra material required for a 2% settlement allowance is shown. Note that the width of the crest at the designed (after settlement) crest height the wall needs to be 4.74 metres wide.

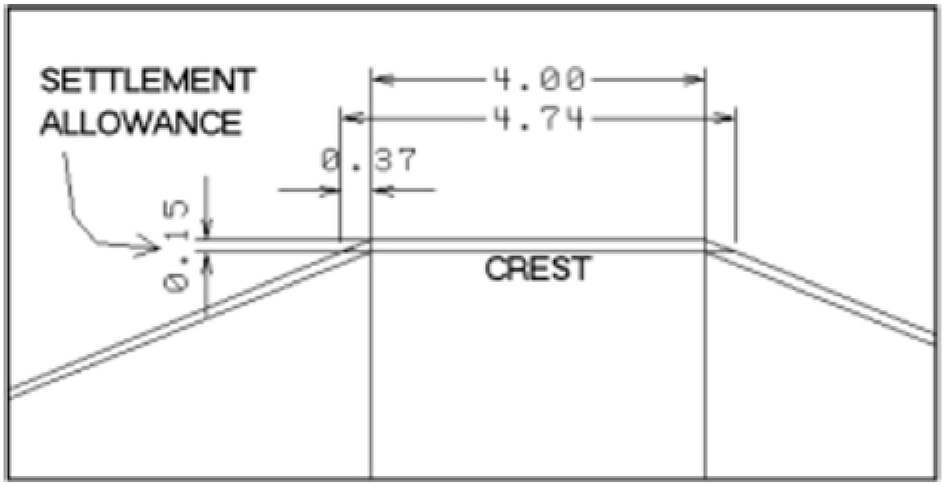


Figure 24 Upper section of an 8 metre wall showing the settlement allowance dimensions.

In connection with the allowance to be made for shrinkage and settlement of the wall of a farm dam, the following may be of interest. During the years from 1944 when we commenced building farm dams on “Yobarnie”, the customary recommendations for settlement allowance was 10%. In about 1954 some controversy arose over (1) the much lower allowances which we have recommended, and (2) the efficiency of bulldozers for building farm dams. In 1960 we invited the University of New South Wales and the Water Research Foundation to observe the construction of a dam on “Yobarnie” and to make any tests they wished. Mr. Trevor R. Fietz, B.E., A.M.I.E. (Aust.) of the university, undertook the work.

The result of the study is reported in the University of New South Wales Water Research Laboratory Report Number 57 titled “Research in Soil and Water Conservation Engineering”, Progressive Report Number 2, 1960/1961, pages 17–19 and dated January 1962. The report states that the objectives of the study were:

a. To observe Keyline methods of dam construction.

b. To assess the general efficiency of bulldozer-only construction in County of Cumberland (Sydney surrounds) soils.

c. To observe the behaviour of the embankment after completions and filling.

It should be mentioned here that the methods of construction were those we have always advocated and were merely our interpretations of good standard practises therefore in no sense, original Keyline methods.

The wall height of the dam was 6.1 metres (20 feet) and it was constructed as recommended throughout this chapter, with two bulldozers. The settlement of the embankment due to postconstruction consolidation was measured by establishing concrete plugs on the crest of the wall and checking their levels at regular intervals. Thirty-three insitu density checks were made and, to date of report nine of the samples from these checks have been subjected to laboratory compaction tests.

Mr. Fietz' tentative conclusions are taken directly from the report.

> "In this case the soil was compacted at a soil-moisture content close to optimum. With Keyline construction (which means in effect particular pattern of earthmoving through the borrow area and onto the wall) the compaction achieved with the D6 (Caterpillar) tractor was close to the maximum obtainable with the Harvard Compaction Test.

Seven months after completion the embankment had settled 0.075 m (three inches) in a wall height of 5.5 m (18 feet), i.e. a settlement of 1.4%. This figure indicates that thorough bulldozer compaction in County of Cumberland soils (earths) makes it unnecessary to provide the customary 10% allowance for settlement."[9] The dam in question has remained in first class condition through the rains of one major flood and two severe droughts.

XIII. FARM DAMS - CONSTRUCTION BASICS

The construction of farm dams according to sound engineering standards presents a significant difficulty for engineering supervision. Large projects being built with small equipment or small projects with appropriate equipment do not pay to have an engineer on hand to supervise the work. Yet supervision is a normal requirement with earthmoving equipment.

In the orthodox construction of large earth dams the material is dumped into the wall site and spread in horizontal layers of uniform thickness along the long section of the wall. Water is generally added to maintain a precise moisture content in the material and each layer is compacted continuously with rollers of various types. The earth for the wall is selected with care and the work is closely supervised.

However, for smaller structures, including farm dams, the restricted size of the job with less equipment moving the earth at a slow rate, the cost of engineering supervision is disproportionately high and is usually dispensed with. Therefore without supervision, material selection, moisture content, layer thickness and adequate compaction often go by the board. The general result is that when orthodox methods are attempted in these circumstances the failure rate is equal to earth dams constructed haphazardly with a bulldozer pushing the earth up the front of the wall to spill over the back until the height, size and shape is reached.

The surprising thing about earth dams constructed on farms in such a haphazard fashion is not why they sometimes breach but why they are so often quite successful. The answer appears to be twofold. Firstly the vibration from the constant travel of the bulldozer back and forth settles the earth on the water side of the wall much better than is generally appreciated. One has only to stand near a bulldozer working on an earth wall to feel the vibrations transmitted through it.

The movement of the machine up the inclined slope on the crosssection of the rising wall tends to form laminations that offer an ideal resistance to possible water movements. For example, the horizontal laminations formed on the long section of the wall by orthodox engineering construction that is not properly supervised could allow water to move between any layers formed and promote breaching of the wall, whereas water is opposed by a sandwich of laminations diagonally across its paths left by the operations of the bulldozer. To move through the wall, water must thus break through and across the many layers.

This line of reasoning suggests a method of earth dam construction that could be supervised by the farmer or a contractor without dependence on qualified engineers.

A. Double Vibration Construction Method.

The Keyline "double vibration" earth dam construction method was devised for the somewhat "larger than usual" farm water storages that are advocated as part of the Keyline development of rural land. However it has applications beyond this field, particularly for town water supply where suitable material for the dam is available nearby, such as from the pond area immediately upstream of the wall site.

Keyline Double Vibration consists of two elements. The first part is a particular pattern of movements of the bulldozer that makes use of its vibrations for consolidating the earth as it is placed to form the wall. The second part is a series of explosive charges that are fired under water immediately the dam is filled. These promotes the final rapid settlement of the wall.

The Lockpipe System is a single or dual water outlet through the base of the dam wall. Through this a large valve releases water for irrigation and a small tap may control selected water for domestic and stock purposes. The system is designed to lock into the foundations of the wall and to avoid the hazard of water moving along the outside of the pipeline and washing through the wall.

In combination, the Keyline Double Vibration dam construction method and the Lockpipe system provide firstly, efficient and economic water storage on farm and grazing land and for local town supply; secondly, the gravity release of the stored water in high volumes for low-cost rapid irrigation or for other purposes, and thirdly, water of the best quality available from the dam when required for stock to drink or for domestic supply.

1. Site Preparation

The first part of the "site preparation" involves the removal, to a position out of the way of future work, of the top soil which now covers the foundation site of the wall and site of the excavation area.

The top soil cover over the foundation area of the wall site is stripped and placed about 6 metres (20 feet) beyond the line of pegs marking the outside toe of the wall. The distance must allow for future unrestricted manoeuvring of the bulldozer between the top soil stack and the outside toe of the wall. The soil over the excavation area is placed the same distance up the valley from the line that marks the excavation area. The objective is to remove only the living top soil cover, about 75 mm (three inches) is sufficient and never much more than 100 mm (four inches).

It is nearly impossible to dig such a thin layer evenly with an unaided bulldozer because the blade will tend both to glide over the grass and "dive" in too deeply. So the whole area is first cultivated to the appropriate depth. Any available farm cultivating implement may be used. If a chisel type implement is used, two complete cultivations at right angles to each other is a most satisfactory method.

The top soil should be stacked where it will not impede the free flow of water through the site. Leave an opening in the top soil banks so that water drainage down the valley remains open. On occasions it may be worth stock piling the top soil above the level that flood water can reach if, during construction, there is a reasonable possibility of sufficient storm rain to fill the dam even with the Lockpipe kept fully open.

a) The cut-off and the Lockpipe trenches.

Next, the preparation of the wall site involves the construction of two trenches. One is the "cut-off" trench, the purpose of which, is to assist the bonding of the wall and the earth below it and to prevent water movement through the base of the wall. It is usually located so as to be exactly below the crest of the completed wall. It is made by the construction equipment and at a width to suit the equipment: 3 metres (10 feet) or a little wider is quite suitable. The trench is made deep enough to penetrate 30 cm (a foot) or a little more into the good material below the site. The second trench of the same width, and constructed by the same means is for "laying-in" the lockpipe. It is located clear of the centre-line of the bottom of the valley and to the down-land side of it, which is the direction toward which the released water will flow. This trench crosses the cut-off trench at right-angles and is dug at the same time. As already mentioned, it takes its level, the top of the pipe-line, from the valley bottom and therefore is located just far enough out from the bottom of the valley so that the excavation into suitable material will bring the trench floor to the correct level. The trench itself, lengthwise, is "dead level" (horizontal). The sides of this trench should be battered back at a 1 in 2 angle so that a vertical wall is not left through the wall parallel to the pipe.

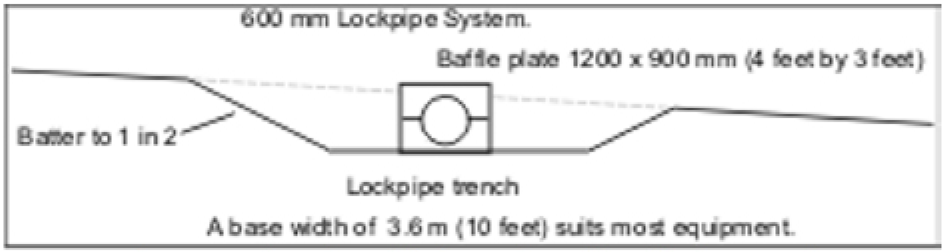


Figure 25 Showing side battering of Lockpipe trench.

The depth of the two trenches, where they cross, is not necessarily the same. More frequently the cut-off trench is the deeper.

Before commencing the placement of earth for construction of the wall, the material of the foundation area, the bottom and sides of the two trenches, is given a rough-up to further assist bonding. Rippers or chisel ploughs are suitable implements for this work and the depth of penetration need be only around 120 mm (4 - 5 inches).

The Lockpipe can then be laid and at the same time the first material for the wall can be placed in position, but must be kept clear of the Lockpipe trench.

Once the cut-off trench is filled, material should be taken from the excavation area and spread across the wall, travelling towards the back line which would already be marked with earth placed during the completion of the excavation of the two trenches.

2. The Lockpipe System

This aid for improved farm water control and rapid release of stored water for flow and flood systems of irrigation, was developed and first used on “Yobarnie” in 1945.

It consists essentially of anti-corrosion treated, heavy steel[10] flanged pipes and gaskets, steel baffle plates, screened inflow cone specially shaped for the inlet end of the pipe line, and a valve for the water outlet. Add to this, the necessary bolts, nuts and heavy duty spring washers.

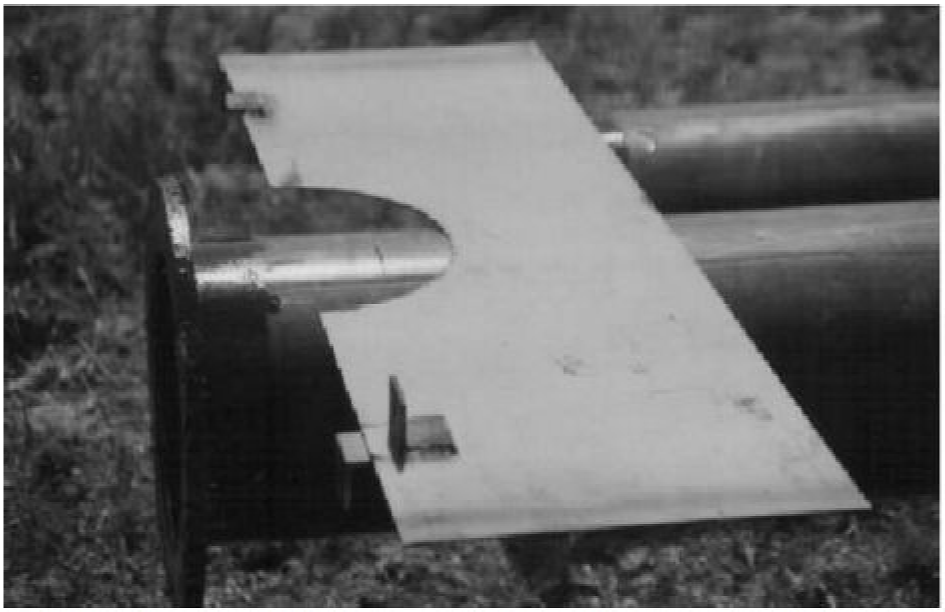


Plate 24 After the flanges are welded to the pipe the weld is painted to minimise rust damage.

Prior to the use on “Yobarnie” of the Lockpipe system, few farm dams had been equipped with pipelines through their walls, other than the Queensland turkey nest type of dam with its small pipe to supply the nearby stock water trough. At that time a 100 mm (four inch) pipe-line through the wall of a farm dam was considered to be unusually large, whereas the present sizes for Lockpipe systems range from 150 to 600 mm (6 to 24 inches) in diameter with even the 200 mm (eight inch) system generally now considered too small.

Although all large Government dams have proper water outlets, the provision of the larger pipes for farm dams was considered too difficult an undertaking for most farmers. Official recommendation was that pipes of any size going through the walls of small farm dams should have concrete cast around them. The concrete collar is still recommended in government plans as recently as 1992 in Queensland. The concrete collars, replaced by baffle plates in the Lockpipe system, assists in preventing water from seeping along the pipeline, eventually washing around it and loosing all the water of the dam and more often, a large portion of the wall as well.

a) Baffle Plates

In the Lockpipe system the cement collar baffle is replaced by the more practical steel (or plastic) baffle plate. If, during construction of the wall, heavy equipment does happen to knock the pipe, damage that could spoil the effectiveness of this system is unlikely. Also if settlement of the foundation area or the wall takes place, as often happens, the steel pipe with its adequate thickness is not broken as would be the case with a more brittle pipe. Anti-seep material is used between the pipe and the baffle plates.[11] The Lockpipe system is placed in position preferably in a wide shallow trench cut by the bulldozer and immediately prior to the building of the wall of the dam over it.

The baffle plates are in two halves and a number of these are positioned along the pipe. They are set up by positioning the lower half of each baffle plate into the earth bottom of the Lockpipe trench. They are closely spaced from near the toe of the wall's inside batter to the centre-line of the wall below the crest, while from the centre-line of the wall to the toe of the outside batter only sufficient baffle plate halves are placed to hold the pipe up and in line. The close spacing of the baffles is at a distance equivalent to no more than one-third of the wall height. The first baffle near the inlet of the pipe should be positioned far enough in from the end of the pipe to be completely buried with about 100 mm (4 inches) of earth above the top of the baffle plate to the sloping batter of the wall.

In the case of a 4 metre high wall with a 4 metre crest width, the baffles would be positioned with the first being about one metre (40 inches) from the start of the pipe. The rest of the baffles can be space about 2 metres apart till past the crest (cut-off) area, one for the join of the pipe and the last plate positioned one metre (40 inches) in from the valve. Generally ten sets of baffle plates or more are required.

The plates act in the first place as a cradle to hold the pipes for bolting up. Care should be taken in placing the individual pipes in the baffle plate halves that the completed line is in its correct position and that the orientation of the holes of the pipe flanges are such, that the valve will be in its proper upright position when bolted on later.

The cradle of baffle plates hold the pipes a little clear of the bottom of the trench to facilitate the proper tightening of the lower bolts and nuts. Heavy duty, 6 mm rubber insertion, gaskets are placed between the pipe flanges and the bolting is safely accomplished when it can be seen clearly that these gaskets have been squeezed out a little. The proper tightening of these pipe junctions is critical and warrants thorough checking.

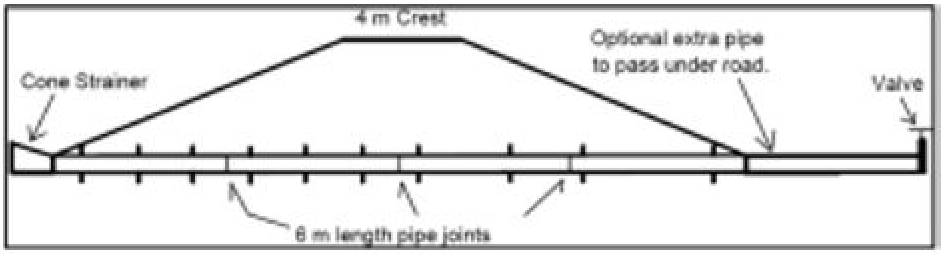


Figure 26 The cross section of a 4 m high dam wall with a 4 m crest, showing the relative locations of baffle plates, the use of extra pipe to allow a road below the wall and the orientation of the cone strainer.

During the laying of the individual pipes in the cradle formed by the baffle plate halves, when the top halves of the baffle plates are bolted in position, the joins are treated with a sealing compound so they form a water tight joint.

Plate 25 Baffle plates prevent water from flowing along the outside of the pipeline under the dam wall. They are bolted in place. The use of a sealing compound around the pipe and between the baffle plate halves prevents seepage.

With the pipe system laid in this manner and all baffle plates complete and bolted, the trench filling proceeds.

The more critical phase of placing the earth around and over the Lockpipe is in the ramming of earth by hand into a tight contact between the bottom of the pipeline and the earth below it. It can be appreciated that no amount of consolidating from above after the line is covered, will have any compacting effect on the earth below the pipe.

b) Filling the Lockpipe trench

In filling the trench, earth is pushed into it with the bulldozer, from end to end and on both sides of the pipe-line, being careful not to cover the pipe or place deep layers of loose material in the trench. The earth is spread by hand shovel from the bottom of the trench to under the pipe-line where it is rammed in firmly. The earth is placed under the pipe and evenly spread over the bottom of the trench near the pipeline. The earth is built up till it is a little higher than the bottom of the pipeline but well below the halfway line of the side of the pipe. When this is done one hit with the rammer covering every place along the pipeline and with the stroke sloping under it, will be sufficient for the first ramming.

Plate 26 Ramming under the Lockpipe is very important.

More earth should then be placed to cover the bottom of the trench to half way up the pipe-line and then another row of ramming, slanted toward the bottom of the pipe-line, completes this critical work.

vary for different diameters, the length chosen should suit the individual lengths and be not less than is specified. There is good value in having sufficient pipe extending out past the outside toe of the wall to enable vehicles travelling along the road above the irrigation channel to get past the dam by travelling over the extra length of Lockpipe between the toe and the valve rather than via the crest of the wall.

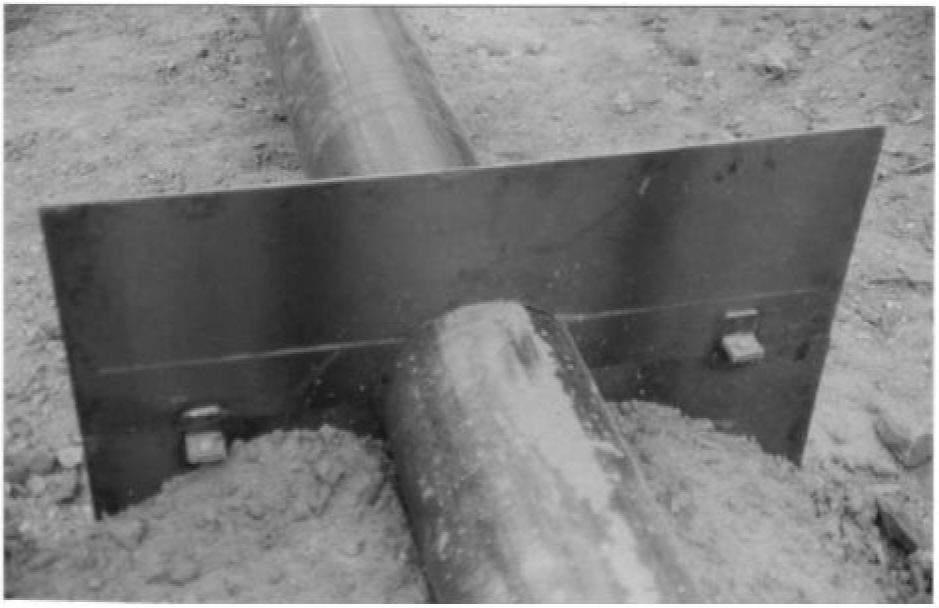


Plate 27 Earth filled to half way up the pipe ready for final pass of hand ramming.

The reason for the hand ramming of earth under the pipe-line is because it can not be done by the earth moving equipment and lose earth under the pipe is likely to allow excessive seepage or worse. Keep this reason in mind and it will be a simple matter to do it properly.

The looser earth covering the bottom of the trench should be “worked down” with a hand shovel and rammed, possibly with a motorised rammer. If done by hand, one good ramming stroke every 150 mm (six inches) is all that is required.

The trench can now be further filled by the bulldozer to a little above the level of the top of the pipeline, with care being taken to see that the top of all the baffle plates are clearly visible. This earth is consolidated on both sides of the pipe-line by travelling over it with the bulldozer while keeping the track on the pipeline side of the bulldozer just clear of the baffle plates. Also, with each of the smaller sizes of Lockpipe systems, up to 10 inches in diameter, or 12 inches for the largest bulldozer, it is possible at this stage to straddle the system, one track on each side. Care is needed to ensure that there is a sufficient height of earth along both sides to hold up the bottom of the bulldozer from contacting the baffle plates.

Before the baffle plates are covered with earth, sighting pegs should be placed centrally at each end of the line. Bulldozer operators needs to be signalled to keep their course of travel on the correct path to miss the now shallowly covered baffle plates. The bulldozer next pushes earth to the Lockpipe system from the sides and at right-angles to the line, in such a way that it straddles in turn, each individual baffle plate. It spills its load across the trench and pipe and continues to travel over the pipe until a point where the front of the tracks are almost over the pipe. The operator should be signalled in this work also. The whole length of the Lockpipe and trench should be covered with about 750 mm (2 feet 6 inches) of earth, then the construction of the wall can proceed normally.

To ensure that each end of the Lockpipe system is not covered up and lost, these ends are marked with a peg or steel post. A large old drum can be stood up at each end of the open pipe as a further marker.

The total length of the pipes of the Lockpipe system should be a little longer than the base width of the wall. Since standard pipe lengths

3. Construction of the dam wall

The earth for the wall foundation area is first placed to cover the whole outline of the base of the wall and then levelled off. Good material is used for filling the cut-off trench and the bulldozer should travel it lengthwise, to smooth out the earth and ensure that each 30 cm (foot) depth of earth placed, is settled and compacted.

a) Earth moisture.

In many types of earth work, moisture conditions are maintained within precise limits.

The failure rate of particular types of construction for earth dams seems to be more closely associated with the moisture content of the earth when it was placed in the wall than with any other consideration factor.

Where the earth is obviously dry the wall is more likely to breach, but if the earth used is moist when placed, the failure rate is low even where the construction methods may appear to be inadequate.

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 when it is in an over-wet condition that causes clays to ball-up and leave air pockets in the wall.

The earth dug for the wall will usually be moist but if it is obviously very dry from drought conditions it should be watered.

Earth moisture tests were made during dam building on our property where the material was a clay with shale below from which it had formed. Good working conditions for evenly spreading the material and compacting it in the course of building, were achieved with a moisture content of 18 and 19 per cent.

The method of Double vibration with its thin tapered layers of earth deposited at fair speed makes improved use of the finer material by placing more of it in the water side of the wall; moreover, the same action appears to make better use of scant moisture by mixing the materials better. Although dry is more hazardous it has often been done of necessity and successfully. Double vibration apparently makes the wall more resistant to drying out when a dam is empty. For instance, following a hot dry spell in the County of Cumberland (Sydney surrounds) twelve empty sizeable irrigation dams on scattered farms breached after filling suddenly in heavy rain and had to be repaired. However of the many empty dams in the area that were built by the Double vibration method, none breached when they filled quickly from the same rains.

It may be difficult to be absolutely sure of the effectiveness or otherwise of specific dam building techniques when earth and weather conditions can vary widely during construction.

Even the cause of a breach in a wall is usually gone by being washed away before it can be seen. However a great deal can be learned about the condition of the earth wall of a dam filled with water when explosive charges are fired underwater near the inside toe of the wall. This procedure is detailed at the end of this chapter.

b) Supervision

Supervision is necessary to see that the bulldozer operator does not dig earth from the foundation area of the wall on the inside of the dam. This is of particular importance in overcoming one of the general faults in farm dam construction. Remember 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 dam is empty. Inside slumping and slipping of the earth of the wall towards the bottom of the dam is sometimes the manifestation of this instability. If earth is removed from below the inside toe of the wall 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 only the stripping of top soil, then there will be a very much shorter length and smaller total area of shrinkage surface and the wall is improved at what is sometimes a point of weakness.

This feature of design is of relatively greater importance in all valley dams as the valley floor slope is steeper. As well as reducing the volume of earth moved, it simplifies both design and construction. The effect is lessened as 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.

Supervision in the construction of a dam is not provided by a man merely watching the bulldozer work. A supervisor, whether a farmer or anyone else, must know first what he wants, and as many people may not have seen a good farm irrigation dam, then he should 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, the methods of work, construction details, 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 an experience bulldozer operator and feel reluctant to stop unplanned or wrong operations. However, an operator in almost all circumstances outside the farm works to a plan and under a supervisor, because such methods of operation have been found to produce lower costs and more efficient work. Moreover, it is quite unfair to an operator to expect him to design and construct a good dam from the seat of his tractor. 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 many years. He should therefore, to get the dam that he wants, have supervision of the designed construction carried out effectively.

c) Maintenance of wall shape

Essentially the wall is built so that the back (outside) batter is maintained in its correct position and slope throughout the construction, while the inside rises from a long flat gradient gradually becoming steeper as the work proceeds. The slope of the outside batter at every stage of construction is maintained at a constant 1 in 2.5 or 1 in 2, as the case may be, while the inside slope of the wall, from the front “cut and fill” line, will steepen from very flat to the final batter as the construction proceeds.

We have found that throughout the whole wall construction of the dam, the downstream or outside batter of the wall should be maintained at its finished batter line by trimming it to shape twice each day.

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.

d) Checking the batters

The outside batter slope of the wall can be checked in several ways.

A large right angle triangle can be made up out of wood. The length of the two sides that join at the right angle are made with the same ratio as the outside batter, such as 1 to 2.5. This triangle can then be used with a spirit level to check the batter. The long side of the triangle (hypotenuse) is placed on the slope of the batter. The short side becomes vertical and on the lower side. The spirit level then is used to see if the top side of the triangle is horizontal.

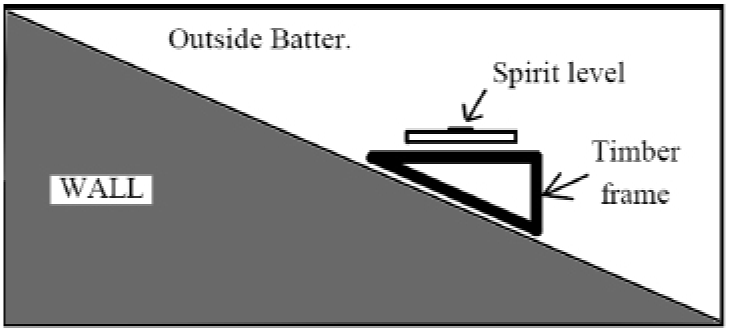


Figure 27 Cross sectional view showing the use of a large, right-angle triangle frame and spirit level to check the outside batter of the wall.

The outside wall batters should be strictly maintained on a straight line at the correct slope, this will produce a plane surface on the outside batter of the wall.

Peg one or several contours across the outside batter of the wall. The pegs should produce one or several straight lines and these should be parallel with the wall's centre line. Pegs to guide the machine operators can take the form of a line of pegs parallel with the centre line of the wall, at a distance calculated to correspond to slightly above the current height of the constructed wall. On these pegs is tied some ribbon at the correct height for that particular distance from the centre line of the wall.

Any area of steeper batter slope should be avoided as it will always be more unstable than the rest of the wall. Settlement of the wall will take place. This may produce, on either side of the unstable area, a steep crack, which tends to undermine the flatter battered earths on each side of the steep area. Undermining assists the movement of the steep material.

Such movements tend to reach a point where they stabilise themselves, although not necessarily so and a progressively worsening slump can breech the dam.

Centre line pegs, lined up with the pegs on either side 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.

4. Methods of bulldozer operation

Many operators can drive a bulldozer well by performing accurately all the required tasks of cutting and filling, and although working hard all the time, still move earth at double what it should cost. We have frequently made tests and conducted trials on such matters and always good

supervision and the techniques which follow, reduce earthmoving costs by an appreciable amount. In the construction of farm dams the concern is in 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 a bulldozer engine is governed to a maximum speed. It cannot overwork or strain itself, so the bulldozer should be worked with the throttle fully open always.

On any job the conditions will influence to what proportion of the machines potential is available. When tabulated these are called job condition correction factors. For example: Moving earth from a “Loose stockpile” has a correction factor of 1.20 so pre-loosening the earth increases the efficiency of the work and saves money. The factor in the presence of a “tilt cylinder” is 0.80 whereas without, it is 0.70, using a cable controlled blade the factor is 0.60. Very sticky material has a factor of 0.80. When estimating earth works rates these and other factors are multiplied together to determine what proportion of the machines maximum production is likely.

The windrows in bulldozer operation are the parallel banks of loose earth left on each side of the bulldozer blade as it moves the earth forward. The action of pushing a bulldozer load forward results in the 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, 24 metres (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 these windrows can be used as slots and an aid to shifting earth faster and cheaper. “Slot dozing” has a job condition correction factor of 1.20.

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 at right angles towards the wall. As soon as the load starts to reduce by spilling in the formation of windrows, the bulldozer stops, 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. The bulldozer reverses back and grabs another full load. Some bulldozers can be equipped with ’back rippers”, which are rearward facing hinged rippers that can be used to tear up the earth as the bulldozer moves backward. The bulldozer proceeds in this manner until sufficiently high windrows 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 into the wall 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 6 metre (20 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 up to 90 cm (three feet) high.

Windrows should be formed at the centre of the excavating site moving out first on one side then the other, so that when all windrows have been formed and used, there is a series of parallel equidistant lines of windrows lying at right-angles to the dam wall.

The next operation involves the destruction of the first series of windrows. 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 as the bulldozer continues operations in this newly formed pair of windrows for the necessary number of passes. The bulldozer then pushes the next windrow of the first series out on either side of the new pass, continuing until all the old windrows are bulldozed 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 construction process.

Systematically 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 in fact more costly.

The bulldozer, except for trimming the earth and in the final finishing off, should always have a full load when travelling to the wall site. A bulldozer travelling onto the wall area with half a blade load of earth is shifting earth expensively.

a) Bulldozer Compaction

A bulldozer is not a completely efficient compacting machine. Nevertheless, the travelling of the bulldozer over the layers of placed earth does give a measure of consolidation and stability to them and can produce a very desirable uniformity of texture in the material. Uniformity of texture is important, as it assures that shrinkage, if it does take place, is also uniform. Cross cracking and longitudinal cracking of the wall will be lessened.

During the construction of a dam, continuous piles or deep ribbons of loose earth in the wall site are to be avoided by having the bulldozer travel forward over the earth as it drops its load in the wall as the operator slowly raises the blade. This material must be regularly smoothed off and shaped up.

The construction of a farm irrigation dam may take as little as two days, or several weeks depending on its size, the implements used, 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, care should be taken to see that the bulldozers do not dig below this level. Avoid creating depressions above the level of the Lockpipe which would trap rain water. The full depth should be maintained only in the Lockpipe area, so that rain water will drain to and through the Lockpipe.

(1) End of each day.

Preparation made at the end of each day’s work should provide against the possibility of damage by heavy rain falling during the night. Some inches of rain could fall on the construction and not prevent work on the following day. However, loose earth on the walls and on the excavation site would, under the same conditions, absorb much water, create ponds, mud and possibly hold up the work for days.

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.

Permanent aligning pegs located well clear of the work when coupled with an accurate knowledge of the true height of the pipe, will enable the inlet to be quickly located.

The Lockpipe should be maintained in an open, free and operating condition at all stages of the construction, although on occasions the inlet of the pipe can be buried to allow the more efficient movement of earth to the wall. The inlet of the Lockpipe should be unearthed, checked and cleared of earth each day before work ceases. Stand a drum in front of the inlet to the pipe. This will stop debris accumulating in the pipe inlet. If the dam starts to fill the drum will float, thereby clearing the inlet of the pipe.

The outside batter and all the placed earth should be trimmed before the daily work ceases. Also both ends of the Lockpipe should be left open to allow possible rainfall run-off to flow out of the incomplete dam.

(2) Rain during construction.

If rain has fallen on the work area the whole of the wall section should be travelled over with the dozer and ripped up if necessary before starting again. This will allow a continuous bonding of the earth as it is placed in the wall to occur satisfactorily. Windrows are then formed again as usual, when the deeper, somewhat drier earth will become well mixed with the smaller amount of wet material. This way uniformity of moisture content and texture is still maintained.

b) Progress of work

During the construction of the dam all bulldozer 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 lowest area of the valley bottom.

The central area of the wall should be maintained as the highest with a slope of about 5% 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 for instance, where the one bank of the valley at the wall is steeper than the other, 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, thus protecting the main fill area of the earth wall.

In a sudden heavy downpour of rain the Lockpipe would also be flowing full of water. As soon as heavy rain has ceased, it would quickly reduce the water level to below the overflow height and then empty the dam. Damage would be at the minimum, even though no expensive safety precautions had been taken.

Dams with only small natural catchments would hardly be affected by some heavy rain. The Lockpipe provides full safety as flood water would rise to less than a metre (a few feet) for a short time. This safety factor is aided by the fact that the diversion channel which will later help to fill the 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 a smaller diversion channel around the area of the dam.

A well-planned and supervised job will look correct throughout the job.

Throughout the building of the dam, the marker pegs should be maintained in position by lifting them out of the bulldozer path when it is necessary. 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, the old peg can be put back in its correct position.

With the earth for the wall being constantly moved in properly designed windrows at right angles to the wall, the site is then 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 obtainable by going back another 5 or 6 metres (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 25% of the earth in any blade load. Bulldozers operating with back rippers are capable of making fairly light work of reasonably tough materials.

Each time the bulldozer arrives at the “cut and fill” line of the wall with a full load, the blade is raised a little to spill a thin layer of earth of slightly increasing thickness toward the line of the back batter of the wall. When the load is gone the tractor continues a little further so that all the placed earth is travelled over by the tracks.

If the load contains lumps of earth, only the finer material escapes under the blade during the early stages of each pass, thus ensuring that the best material goes where it is needed most, on the water side of the centre line of the wall. The bulldozer ’run’ is usually in second gear. This fast spill run also promotes uniformity of texture from the improved mixing that in turn favours even settlement, while the vibrations from the fast return of the empty bulldozer down across the rising wall after every pass further ensures the consolidation of the earth.

The inside batter of the wall during construction is not treated in this manner. It starts off on a very flat slope, gradually increasing in steepness, until it finally reaches the correct batter on the completion of the wall as shown in the following figure. Notice the thin layers and appreciate the obvious high compaction on the critical inside toe of the wall. The only time the bulldozer must negotiate a slope at the full grade on the inside toe is in the final stage of wall forming. This material can often be obtained from just in front of the inside toe.

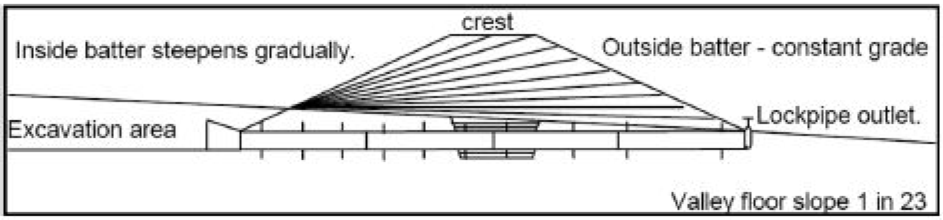


Figure 28 Showing the progressive layering of the earth in the wall and how many thin layers and hence great compaction occurs where most needed.

A continuous check with a level and taking measurements, ensures that the right amount of material is in the right place and taken from the correct position in the excavation area. The central 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.

Batters should be even and continuous throughout with straight lines up the wall.

(1) Things to avoid.

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 also a tendency for some bulldozer operators to push all the earth of the blade-load into the wall and leave it as a loose mound. This can be avoided by the operator 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 on to the wall site, the result being that much loose material is spilled over the back of the wall. This loose material in a finished wall tends to absorb a lot more rain-water 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 as 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.

Avoid unintentionally spilling earth down the outside batter.

5. Finishing Stages

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.

It is important that the excavation area be smoothed into a natural shape to conform to the valley area of the whole dam.

a) Top soil replacement

When the excavation area has been smoothed into a natural shape the raw earth is cultivated with a chisel plough[12] and then covered with some of the stock-pilled top soil which was previously moved from the surface of the excavation area. The remainder of this top soil is used to cover the inside batter of the wall.

The top soil which was stripped from the wall foundation area is brought up over the wall to cover the outside or downstream side and the top of the wall.

It is worth noting with regard to the depth of the replaced top soil that about 50 mm (2 inches) of soil cover is the maximum that is required and the minimum depth is gauged simply by the fact that the subsoil should not be visible through the top soil covering.

Top soil should never be used to fill low spots in the wall left through inadequate supervision.

The crest of the wall should be finished off with slightly rounded 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 will cause little ponds, which eventually break in one particular spot causing the water to flow down the wall in a concentrated stream. Further rain falling on the wall takes the same path and sufficient damage could take place with 25 to 50 mm (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 ripped with a chisel plough in a single-run cultivation about 75 mm (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 starter fertiliser.

Hand finishing of the top of the wall to leave a good shape and aid the germination and growth of the grasses is well worthwhile. Slight ridges of loose earth can be raked out.

Do not leave the batters of the wall “back bladed”[13] and smooth. It looks neat but only until rain falls on it, then it washes and gutters quickly form.

It is better for the batters to be track walked with bulldozer travelling up and down the wall with the blade lifted off the surface. The tracks will leave the wall with a pattern of hundreds of horizontal tracks that trap moisture, resist wash and promote pasture growth on the wall.

Plate 28 Grass is growing in the tack marks left by bulldozer in the topsoil on the batter slopes of the wall of a dam.

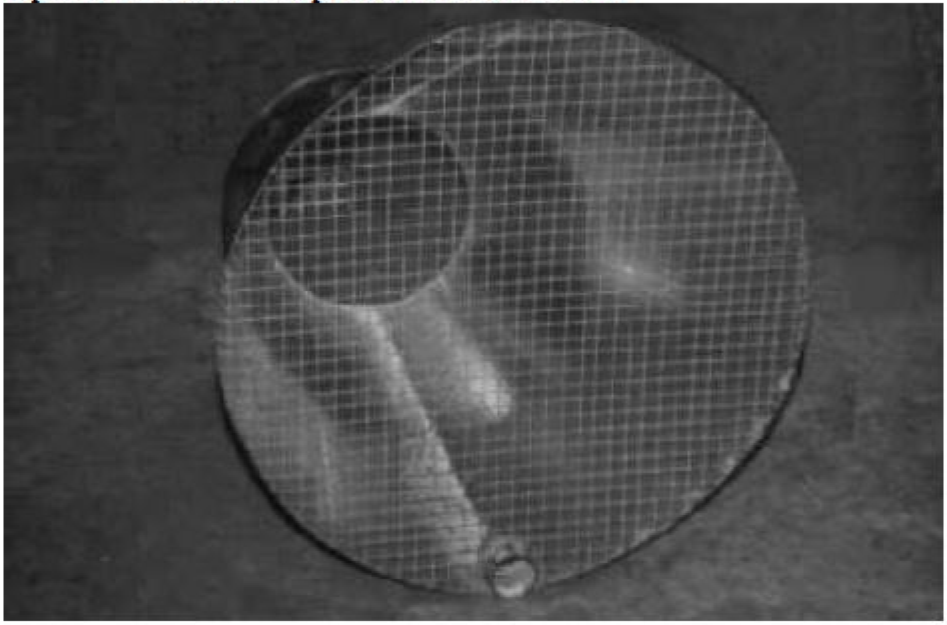


Plate 29 A "Cone Strainer" for the inlet of the Lockpipe System prevents blockages and increases flow rate. Note the 75mm (3 inch) socket for the Flota-filta pipe.

b) Finishing of the Lockpipe System

The cone strainer is coupled to the flange at the inlet end of the pipe on the inside of the wall. A rubber gasket may optionally be used between pipe and the cone strainer. The inclined section of the cone strainer should to point upwards in the upstream direction. The upward tilt acts as an additional safety measure to preserve a free and full flow of water in case there is a slight slip of wall material through any cause.

The cone strainer's opening is up to nine times the Lockpipe size, and screened by heavy mesh. The speed of the water flowing into the volume strainer when the Lockpipe valve is open, is therefore very much slower than the speed of the flow through the Lockpipe so that any rubbish which can enter the strainer will flow out through the pipe. The cone strainer also induces laminar flow in water entering the pipe, which reduces turbulence and increases the rate of flow through the pipe.

The outlet valve should be coupled in the same manner as the strainer, but on the downstream end of the Lockpipe then tightened up and closed. All surfaces, gaskets and flanges should be clean and no earth left in the end of the lockpipe. If care is taken during the installation of the Lockpipe the holes in the flanges will match up with the valve and it will fit in an upright position.

Valves may be provided with a 50 mm (two inch) outlet socket welded on the water side of the valve closure so that water is always available for items of smaller supply such as stock troughs. The water sitting in the main Lockpipe system will however become stale and bad smelling, making it unsuitable for occasional domestic and stock use. The potential problem is solved by extending the two inch line through the centre of the main Lockpipe system and extending sufficiently into the dam for the inlet to be suspended by a float buoy, so that the 50 mm (2 inch) line can draw fresher water from near the surface of the dam. This twin water supply is called the "Flota-filter system". It is simple to construct and is detailed below.

c) The Flota-Filter.

Inside the main lockpipe, and on to the end of the two inch socket, an elbow or sweep bend fitting should be attached. Onto this should be connected a rigid 50 mm (two inch) pipeline that extends through the full length of the Lockpipe system and out through the cone strainer, into the pond area of the dam. Ordinary poly pipe can be sucked out through the main valve and unless it is firmly anchored at the cone strainer it should not be used in place of the rigid section of pipe through the Lockpipe system.

The rigid pipe needs to extend beyond the cone strainer by about two metres to keep this end of the pipe well clear of the cone strainer. At this point the 50 mm (two inch) pipeline can be changed to a flexible material which is long enough to easily reach the surface of the dam when it is full. To the end of this flexible section, is attached a filter, then a length of stout chord and a float. This “Flota-filta” is intended to provide high quality water, drawn from the better water near the surface of the dam. The cross sectional view following shows the layout. The Flota-filter is a concept that works.

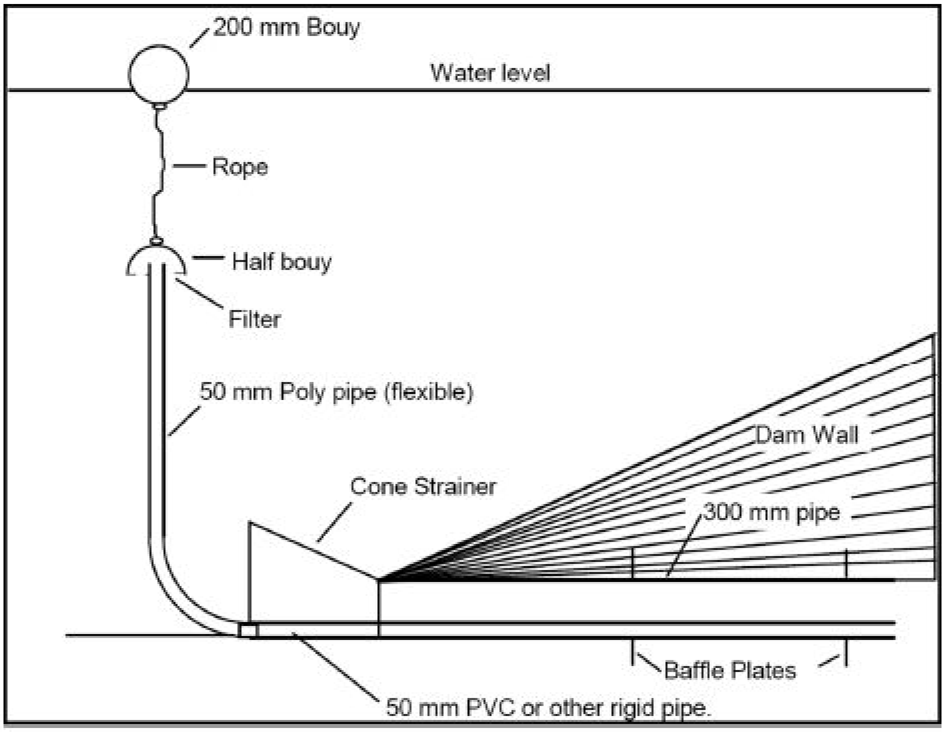


Figure 29 A cross section of the inside toe of the wall showing the Flota-filter components.

6. Explosive vibration of the wall.

Nearly all earth dams seep some water, particularly for the first year. Double vibration dams may also seep, but it is not unusual that seepage does not occur or is greatly reduced or stopped within ten days after the wall is vibrated by explosives.

Vibrating the wall is done with a series of small explosive charges. These are fired under-water near the inside toe of the wall and provide a series of vibrations to quickly settle the wall. The consolidation and settlement of the wall will be accelerated. This will help seal the wall and can prevent leakage from occurring.

The vibration force transmitted through the wall by explosives depends on the depth of water. Half a small plug of gelignite may give an adequate effect when fired under 6 metres (20 feet) of water, but use a full plug when the depth of water is less than 3 metres (10 feet). If the water is only one metre deep, one plug will not produce effective vibrations in the wall.

Select a spot near the deepest part of the dam for the first shot. After lighting the fuse, which should be about 300 mm (a foot) long, the charge is thrown so as to lob into the water directly above the cut and fill line of the up from the inside toe of the wall. For example, if a dam has a 1 in 2.5 inside batter and where there is 3 metres (10 feet) of water to the start of natural surface, the charge is thrown to hit the water about 7.5 metres out from the water's edge at the wall.

The operator should stand flat-footed, facing the pond on the water side of the wall's crest and wait for the explosion. The explosion vibrations will be felt as a shudder in the feet, but can be missed if the heels are off the ground. This first shot is satisfactory if the vibrations are felt quite positively in the feet. If not, the charge may have been thrown too far out into the water and come to rest on the solid bottom beyond the inside toe of the wall. Another shot is then fired to replace the ineffective charge.

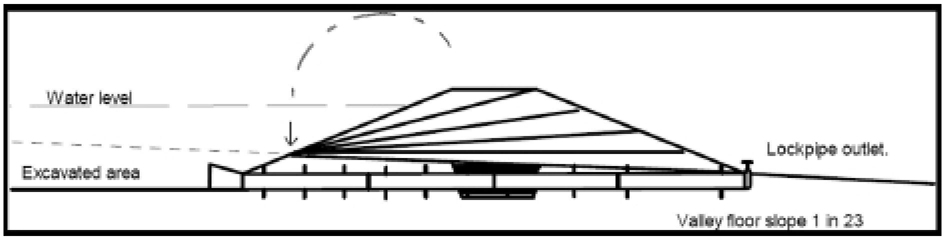


Figure 30 Showing where the explosive charges should be lobbed into the water and where it is intended to explode.

Plate 30 A "Double vibration" depth charge explodes. In this case using a single stick of gelignite. Photo taken at maximum splash at the moment of the explosion. Gas bubbles soon erupt. Usually no explosive splash occurs unless the water is very shallow.

Each charge should be fired separately. A rule adopted since the time when a lit fuse in the water was extinguished, apparently by the underwater shock wave from another stick of gelignite when it exploded. The unexploded gelignite remaining under water in the dam was somewhat disconcerting. No one volunteered to duck-dive to find it.

There is a general formula for vibrating the wall, viz. charges are fired at intervals along the wall equal to the depth of water. Thus in a dam with seven metres of water above the Lockpipe, there will be seven metes between charges, five metres for others and three metres apart as the dam shallows towards the edge. There is not much point in firing charges in less than 1.5 metres of water, unless there is a considerable length of shallow wall, in which case the charges need to combine two plugs or more.

The complete explosive operation is carried out after a satisfactory trial shot. Prime all the charges and lay them out along the batter side edge of the crest at their proper spacing ready to be picked up, lit and thrown into the water. A charge is used each side of the cone strainer where only a 'direct hit' could cause slight damage. With each shot, the operator can interpret the explosive vibration effect. If the uniformity of the compactness of the earth varies at all it will be noticed through the soles of the feet. With the experience of only a few shots, an operator can compare the different effects quite confidently. For a given height, better compacted walls vibrate less.

Plate 31 Wave action from two days of explosive treatment caused the two lines across the wall and show the rate of leakage which prompted the explosive treatment. Below the lines, the pockmarks show where the various charges exploded. The explosive charges eventually revealed that the dam was leaking through a mud stone seam in the base of the excavation area and not through the wall. The mudstone area was ripped up, removed and spread and the cavity was refilled with more suitable material and compacted.

(See Google Earth 30°35'50"S 152°10'24.08" E)

XIV. FARM ROADS

Roads through the landscape are constrained in their location by the more permanent features. Roads are fourth in the Keyline Scale of (relative) Permanence. The main farm roads are influenced in their location by the climate the land shape and water movement control lines. Water is usually a problem to road engineers and increasing volumes of flowing water are hazards to roads. Tarfficability in wet weather and maintenance cost are vitally affected by water. Roads can be positioned so they are protected by the channel system or generate additional run off water into the channel system. Contour roads require less energy to travel along. This is an extra bonus to all those travelling under their own power, be they stock or people on foot or bicycle.

A. Along the boundary fences.

Boundary fence lines are commonly located on compass bearings and rarely do they suit the landscape. Roads along these lines are likely to be self destructive because of the water flows that they intercept. However for fence maintenance and fire control an access road along the boundary fence is generally desirable.

B. Located on watershed lines

The centres of main ridges that form a part of the boundary of the secondary valleys, are neutral lines of no flow, and being high and dry are very suitable sites for main roads. Use the centre line of primary ridges too as these are also water divide lines. Roads in these locations do not cut across natural flow lines and water can be channelled away from both sides of the road.

C. Located by channels

Those roads that run across the land can follow the channels and other contour guide lines.

The influence of the diversion or feeder channels of Keyline (formerly: water conservation drains) and the position of irrigation channels and irrigation areas determine the sites and general patterns for work roads and are arranged as follows.

1. Below feeder channels

Generally it is best to position roads below graded feeder channels as this is an almost completely dry location. No pipes will be required, the road is level to travel along and gully crossings have already been made. These roads lead directly to the crests of dams that span some valleys.

2. Above irrigation channels.

Roads can be positioned parallel to and on the upper side of any irrigation channel as this is the drier side.

a) Crossing Irrigation channels.

(1)Pattern irrigation channels.

Crossing hill side irrigation channels may be easily done by using some railway sleepers as a bridge. The sleepers can be removed for channel maintenance. Alternatively a concrete box culvert may be used. If a piped channel crossing is being contemplated, make sure that it has a cross sectional area at lease equal to the channel cross section. Do not simply match the size of the pipe under the wall of the dam. The Lockpipe water is under pressure so the velocity of flow through the Lockpipe is much faster than along the channel. The slower speed of flow requires a bigger cross section area to carry the same rate of flow.

(2)Flood-flow channels.

Crossing Flood-flow irrigation channels is usually avoided, however when it is required, simply broaden the bank. The steering banks below the channel will determine the path of the road and the point of crossing the channel. At this point the bank of the channel requires broadening. It is important that any material placed on the road in the channel does not raise the bed of the channel.

D. Elsewhere

Other roads may follow the lower boundary of an irrigation area.

Another location for roads is on either side of the natural breaks in the land, namely the watercourses. Some of these considerations have always influenced the positioning 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 provide a guide so positive that all road sites are selected to advantage because all factors in their positioning are understood. Farm roads while serving their purpose, change the natural drainage pattern either towards destruction or preservation of land profiles. In Keyline planning it will be seen that the position or sites of farm roads becomes natural, obvious and constructive.

XV. TREES

A. Trees in the Keyline Scale of Permanence.

In the Keyline scale of permanence trees are ahead of permanent farm buildings because their lasting qualities exceed those of the buildings. It is common to see a group of trees in an area where a farm homestead once stood.

On un-cleared land the trees were part of the environment that produced and now protects the soil. In no circumstances is the complete destruction of all timber trees and the associated smaller growth necessary or desirable for farming or grazing pursuits.

Trees become part of the ordered site planning for the whole landscape when the decisions on the tree removal and planting follow the consideration of climate, land shape, water supply and farm roads.

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 results 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. Trees will all too often affect quite a sizeable area of crop or pasture land. The tendency of farmers is to get rid of the trees. 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. Sometimes this is called “die-back”.

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 but this can be improved upon.

B. Contour strip forests

Contour strip (corridor) forests are one of the hallmarks of Keyline planning.

From the distance, looking across the verdant landscape of Keyline pattern tree clearing, it looks like full timber.

Plate 32 Keyline dam and contour tree belts in Southern N.S.W.

The clearing can not be readily seen. It is only when one enters the landscape that the cleared land is seen. A better view of Keyline tree lines is from above. When looking down on land cleared to the Keyline pattern one may see the beautiful winding pattern of the strips of timber.

Plate 33 Contour timber belts southern N.S.W.

The clearing and tree planting program leaves wide bands of strip forests sandwiched between wider strips of pasture and crop land. Wide bands of timber may highlight the main ridges of the property. This is a truly beautiful sight.

Normally Keyline strip forests follow the pattern set by the properties major water conservation and gravity redistribution system and the road layout.

Plate 34 Timber belts on Nevallan in 1954 above a contoured farm road. A feeder channel above the trees set the location of both. See Google Earth 33°33'58.52"S 150°41'32.58"E)

With Keyline planning the major water control structures and road systems are sited prior to the consideration of the tree clearing and planting layout. Water first, then roads, then trees and buildings followed by subdivision fencing design and finally developing biologically fertile soil.

The timber belts may vary from several rows of planted trees up to 50 metres or maybe more of undisturbed native timber. On our own properties the belts probably averaged around 30 metres wide. However each property is unique and should be planned with its uniqueness in mind.

Contour tree belts[14] can be seen on many properties in Australia.

1. Effect on pasture growth.

On our own properties tree belts which were left on country that had been badly eroded abandoned and covered with only the poorest re-growth 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 program. From that time onwards the trees had a beneficial effect on the pasture, and the notable 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.

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

2. Climate modifiers

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 planted 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 walled 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 our former properties are not only beneficial but add to the beauty of the landscape.

3. Steep country.

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. A heavy rain storm following a fire in a timbered area will quickly wash away the ash and exposed soil and often creates gutters.

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 keep it warmer in winter. Trees improve the microclimate. They protect the land from desertification. Reestablishing adequate timber cover may logically be expected to improve the climate by the reversal of desertification. Keyline timber clearing and planting is intended to derive the greatest benefit from trees for the whole of the farm.

Trees should be left in strips or belts wide enough to keep some semblance of forest conditions in the timber for its normal healthy growth.

Steep country should not be left in full timber but partially cleared leaving timber belts to serve as wind and fire protection for the property.

4. The first belt of timber.

The Keyline design for the water resource development and the road system is the planning guide for clearing. The first timber belt may be twenty to thirty metres (or yards) wide and is left or planted parallel with the main diversion channel.

If continuous strip of timber is desired it must be positioned on the upper side of the diversion channel. Such a continuous belt of timber will wrap around the water line of any dams along the channel and the sheltered water will have reduced evaporation. If the strip forest were positioned below the diversion channel, each dam the channel passes will cause a break in the tree line, which can be seen in the image below.

Plate 35 Nevallan in January 1993. Note the stepped positioning of the tree belts. The tops of the trees beyond the dam rise to the base of the trees in the centre left. The tops of these trees reach to the base of the highest strip (upper left corner.)

The road location relative to a diversion channel is usually parallel with and below the channel. There are several benefits from this location:

- It is a relatively dry location because no water is likely to flow over the road unless excessive runoff exceeds the channels flow capacity.
- Anyone travelling along the road will have a more commanding view of the land below the channel if the tree strip is above the channel.
- The road will lead directly onto the wall of any dams along the channel.

In a minimum clearing operation, where only the dam, irrigation channel, irrigation area, diversion channel and the roads are cleared, the strip of land between the two channels can be left as full timber.

In very steep country the bank or even the bed of a diversion channel may serve as the road.

The first tree strip beside the diversion channel may form the guide for the establishment of other tree belts made parallel *in the vertical plane* with this line.

Tree belts may also be located beside the irrigation channels. In this case the tree belts are above the irrigation channels

Where there is no diversion or irrigation channel that can form the basis for the timber strips then the Keyline of the most significant valley is used as the foundation of the design. When this is not available then the top side of the lowest contour line spanning across the most significant ridge would be used as this is a primary cultivation guide line and would be a suitable starting point.

5. Locating other timber belts.

From the first belt of timber other parallel tree lines, at a selected vertical intervals apart, are left or planted on the contour or a suitable grade. These other tree lines may be both above and below the first line of timber.

The height of the trees determines the vertical interval between timber strips. If trees are or will be 12 m (40 feet) high and the vertical height occupied by the land in the width of the tree strip is 3 metres (10 feet), the timber strips would be vertically 15 m (50 feet) apart. This gap provides very effective overall wind protection for all the land and locates the timber belts closer together in the steep country and farther apart as the country flattens. Even in very flat country of low scrub or Mallee only 3 to 5 metres (10 to 15 feet) high, a similar formula for clearing will provide greatly improved farm conditions.

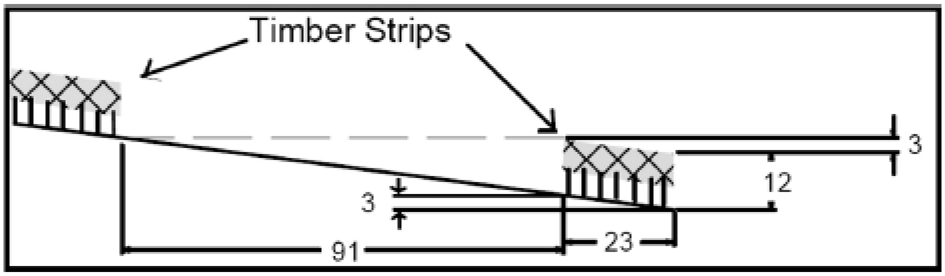


Figure 31 Cross section of timber strip spacing used in the text. Ground slope is 1 in 7.5.

The spacing of the tree strips changes with the slope of the land.

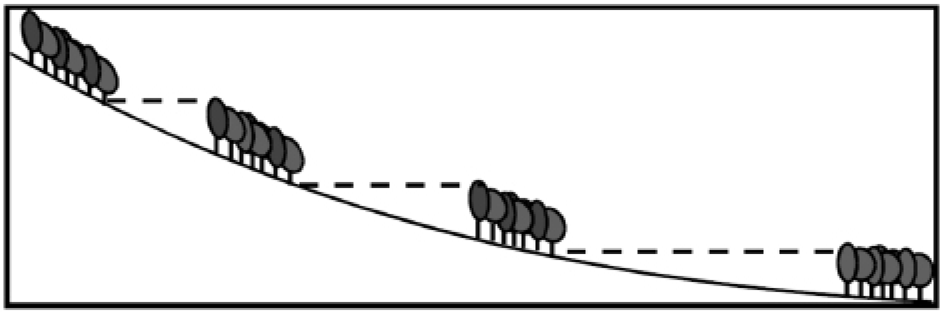


Figure 32 The spacing of timber strips changes as the slope varies. (Diagram concept from Rix Wright, "Knockalong", Delegate, NSW.)

Timber strips left like this are a valuable aid to soil fertility, part of which comes from the supply of deep minerals that they bring to the surface. In wet weather cattle will only stay on soft pasture ground long enough to feed. Then they return to the firmer ground of the undisturbed soil in the timber belt. The comfortable conditions in the timber belts will, to a large extent, keep stock off soft wet ground.

The farmer, of course, should leave his wheel machinery in the shed when the land is wet. Thus compaction of the soil, which is one of the great destroyers of soil fertility, is minimised. Two of the most effective land compacting implements are the sheep-foot roller and the multiple pneumatic-wheel roller. The rural equivalent of these are the farmer's stock and his wheeled farm implements.

By clearing steep country on the Keyline pattern more and better grass areas are available and better timber will grow in the timber belts. Very short steep slope country is always of greater value when cleared and Keyline developed. This is because Keyline absorptionfertility methods applied above the timber strips greatly increases the moisture-holding capacity of this land, which provide the timber with better moisture. Timber growth is considerably accelerated.

Timber belts 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 belt 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.

6. Ensuring perpetual timber.

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 is assured.

If tree strips of even width are desirable, then a contour line, or grade line, forms the lower line of the strips on ridges and above the Keyline of any valleys. A line, parallel to this, forms the upper line. In a valley below the Keyline it is preferable to have the upper line of the strip on the contour or grade line and the lower line parallel to it. The exception is adjacent to the irrigation channel where the timber strip is usually above the channel.

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 design 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.

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 further special attention.

a) Induced timber strips.

Two interesting incidents from the early years of Keyline development will serve to illustrate possible low cost means of growing valuable timber strips.

- During the construction of several water conservation channels all except one were harrowed and fertilised. A directive was given that this one channel was not to be treated 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 six metres (twenty feet) high and all of one species covered the drain.
- In the drought of the same year (1944) several runs with a 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 channel less than two kilometres (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 planted 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 of four years old the majority will survive stock damage.

b) Strip forests sown by water.

Sometimes strip forests occur unintentionally, as was the case with a contour strip forest that developed around the flood storage level of the Burrendong dam in Central N.S.W. When this large government dam was first filled the flood gates were kept closed and the water level raised and held perhaps 5 or 10 metres above the normal “full” storage level. The effect of this was to drown any timber still with in the pond area of the dam. Some varieties of these trees made one final drop of seed and these seeds, carried by the wind across the water of the dam became sown around the waters edge. What developed was a truly beautiful strip forest. Unfortunately much of this re-growth was destroyed by farmers not realising what a beautiful asset was in the making. However there is still some sections of this beautiful contour forest corridor still to be seen around the lake. Small scale waterline forests have occurred around the waterline of other farm storages. The prerequisite seems to be that some trees are left to drown in a new dam. Such beautiful accidents however are of minor importance compared to the potential for the development of contour forest corridors through out the Australian landscape.

There is every indication from the implementation of Keyline design that tree belts, where located in respect to land shape, water and road lines, 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.

In no circumstances is the complete clearing of a property necessary or justified. Unfortunately trees, even odd trees, have been seen to greatly restrict the area of grass growth, and so 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.

c) Planted trees.

(1) Tree purchases.

Generally a small Australian native tree may cost around one dollar[15] to purchase but may cost twenty times this amount 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. Mechanical planting of thousands of tiny trees is a practical reality.

(2) Land preparation.

In large or small paddocks without trees that are to be Keyline improved a strip of timber five to ten tree-rows wide can be planted. The following procedure has produced good results:

After completing the Keyline absorption-fertility program for the paddock, or at least one complete Keyline pattern cultivation of the paddock. Mark out with a single rip the first tree row position. A single tyne is allowed to penetrate deeply through the ploughed soil. On the return run with the tractor place the down-land side rear wheel in the upper wheel track of the first run and travel the tractor back without ripping. Turn around and again with the downhill side rear wheel in the upper 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 rows and one or two cultivations are done during the first year after planting the young trees.

(3) Build the soil fertility first.

A delay in planting for a year while the biological fertility of the soil improves from a cultivation after each rain will be quickly offset by the faster growth of the trees. So clearly the preparatory cultivations should take place over some months prior to planting the young trees. The trees can be purchased from Departmental forestry nurseries. Plant the young trees well into the moisture zone without breaking the soil on the pots. 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. A spacing of 2.4 m (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 unploughed country when the paddock is closed for cropping. Tree growth will often flourish on this strip and form a valuable tree belt.

Ken (left) and Neville Yeomans in 1954 in a newly planted strip of sallow-wood and other gum trees. The trees were 150 mm (6 inches) high when planted in the spring and the picture was taken in the following autumn. The strip contains about 3,000 trees.

Plate 36 Upper photo, Ken Yeomans with his eldest brother Neville when the trees were 6 months old. Lower photo shows Ken and the same trees viewed from the opposite direction taken in 1993.

C. Fire Prevention - the natural answer.

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.

1. Stock save themselves

Rix and Jenny's grazing property was on fire. They were away fighting other fires in the district. Their stock however were saving themselves thanks to the Keyline pattern tree clearing that had been done many years before. The property where this happened is in the Snowy Mountains near Bombala.

Grass scrub, and forest fires are a common characteristic of our landscape. The eucalyptus forests of this land are a natural environment for fire. The leaves are loaded with inflammable oils and in many varieties the lower limbs of the trees are shed off the trunk and fall to accumulate into a mass of timber litter that will readily burn.

Nothing can compete with the gum trees for fire survival. Many of the species require fire to crack their seed coating before the seeds to be able to sprout.

Plate 37 The re-growth after a bushfire is spontaneous to eucalyptus trees and leaves seem to sprout from all over the tree trunks.

When a bush fire gets started the fire forms a "front"; a long advancing of wall of flame, sometimes leaping ahead of itself. When this inferno enters a property, if all the trees have been cleared the fire still remains as a raging wall of flame.

Even when some or many of the trees are left in the all too common tree clearing pattern of leaving some individual trees that are particularly pleasant looking, the fire still advances as a wall of flames. Although random clumps of timber may make for some break up of the advancing flames, Keyline planning has a better way.

What was it about the Keyline tree clearing pattern that can allow stock to save themselves from fire?

On the Keyline planned property, referred to above, the tree clearing pattern produced a layout of contour strip forests that completely broke up the advancing wall of flame. The winding strips of timber and pasture enabled the stock to freely move from open country to forest and back again. The stock avoided the flames themselves and it is just as well that they could for the owners could not help them. On this occasion the property owners were away fighting other fires, along with the rest of their neighbours, in an adjoining district. On their return they did manage to save one of the homes. Not all the animals escaped the flames, only the ones in the Keyline cleared paddocks. Sheep in open country or full timber had no chance as was the case for virtually all the stock on the neighbouring properties. Their animals were wasted, engulfed in the relentlessly advancing wall of flame, there was no escape.

The property's natural bush (timbered) areas were totally devastated by the fire and particularly so on eastern slopes where the fire front moved slower and thus burned more intensively.

Plate 38 After a bushfire the evergreen Australian landscape takes on a false autumn (fall) almost bronze coloured appearance.

On inspection of the bush areas after the fire revealed the impact on the native (and other) animals; burned bodies of wombats, kangaroos, foxes, hares were seen in abundance. The soil was also seriously effected in these areas. As is so often the case after a severe bush fire the next rain was very heavy. Soil losses in the natural bush were severe. In the areas of the Keyline contoured tree strips this loss was significantly less.

2. Stock put onto wet land.

On another occasion fire was threatening to over run sections of the Megalong valley near Katoomba in the Blue Mountains west of Sydney. A Keyline project on one of the properties in the area had only reached an early stage of implementation. The first large farm dam was in place, equipped with the usual 300 mm (one foot) diameter Lockpipe System under the wall. The dam had operational feeder and irrigation channels and was being used to supply water, all by gravity, to the main irrigation area which had been cleared and was growing healthy pasture.

The fire was coming, what did the neighbours do? Many mustered all their stock and freighted then out of the danger area. What happened on the Keyline designed property? The owner quickly watered his irrigation paddock, at a rate of perhaps three hectares per hour, saturating the whole area. He then moved his stock onto the wet country, thus placing his stock in the only fire proof zone in the district. As it turned out the winds changed and the immediate danger passed, but the surrounding properties then faced the added expense of freighting their stock back again. Mustering and freighting stock away from a threatening fire front is always costly, in time, energy and other ways, but it can still be a fruitless unproductive exercise. Such waste can be avoided by Keyline development.

3. Proven priorities.

There is a right way to develop the ultimate potential of any farming and grazing landscape, all the rest will fall short. By using proven priorities Keyline planning makes it simple. The Yeomans Keyline approach to property planning can reveal the truth about the hidden potential of one of your greatest assets, your land. Fire control and erosion control are incidental benefits.

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

D. Soil and Trees from the City Forest

The natural rain forests were one of the abundances of the created world. But they are now alarmingly depleted and these forests are being destroyed at an increasing rate. Their restoration and expansion is critical for the safety and preservation of the total environment.

The deepest soils on the face of the earth was in the natural rain forest. The forest soils were not always the most fertile when judged on their capacity to produce in abundance the feeds of the high quality complete proteins. But they were tremendously absorbent.

Rain forests occurred wherever the conditions for their development had been suitable. They needed an adequate and regular water supply, mild to hot conditions with no long dry periods. The trees did not usually intrude into the great fertile grasslands because these were subject to drought.

Vital in landscape design for the city and the countryside are trees and deep soil. In nature the deep soil and the trees developed symbiotically whenever the climatic conditions were right and there was no time pressure.

1. Urban effluent disposal

For urban effluent disposal there is rarely any such deep absorbent fertile soil and there is a time pressure. Fortunately the response of the inhabitants of the soil to good living conditions and abundant food are very rapid. These conditions can be promoted and controlled. In only three years deep fertile soil has often been developed from poor soil and subsoil.

However for the development of the soil for an effluent disposal “city forest” there is a different goal. Not just 200 mm or even 400 mm (eight or sixteen inches) of soil but the rapid development of 1,200 mm, 1,500 mm (four or five feet) or more, of fertile and absorbent soil.

The preparation of the land for water flow and for planting and irrigating of the soil and the trees are soil making procedures. There will be no waiting around for these things to happen. The natural responses will again be rapid.

2. Practical experience in tree planting.

Some experiments of our family in growing trees and experiences to do with rain forests are recounted in order to confirm the validity of the City Forest and the strip forest for their role in landscape design.

a) Failed tree planting.

A hundred or more trees were planted a year after the purchase in 1943 of the original Keyline properties at North Richmond N.S.W. The ground was opened up with a post hole auger and the young trees were watered for a time. The planting was a failure.

b) Successful tree planting.

Immersed in the problems of water, no further attempts were made to grow trees for a few years. Later because of interest in the idea of treated round posts for fence posts it was decided to grow a perpetual forest of fence posts. This planting was so successful that in three years there were more trees ready for posts than could be used. When some of the trees were cut, a selected re-growth sucker was left to grow from each stump. They were large enough for posts in only two more years. The trees were spotted gum, (Eucalyptus maculta).

Of course this planting had been done differently, because in the meantime something had been learned from our soil experiments.

On our property the poor shale derived soil, the exposed subsoil and the yellow shale was ripped up with an early version of a chisel plow and sown as for pasture and a soil development program was managed for a year. One significant departure from our standard pasture treatment was that the area was chiselled when dry enough after every significant fall of rain for one year.

In each successive cultivation the penetration of the chisels was a little deeper. The lines for the trees were finally ripped 400 mm (16 inches) deep, which was the limit of the equipment. By the end of the year the clovers and grasses had become healthy looking and vigorous, the poor soil material now looked like soil to a depth of about 175 mm (7 inches) and there were some earthworms to be seen. In this moist soil the young six leaf trees seedlings were planted after having been watered the evening before in the tubes in which they were grown by the New South Wales Forestry Commission. The plants received no water at planting time and only rain thereafter. The soil between the tree-rows was chiselled twice during the year after planting, by which time the roots of the young trees had gone down over 500 mm (20 inches). Two years after the tree planting the soil was found to be loaded with various grain and thread-like fungi, the character of the earthworms had changed to big and fat and clover plants persisted among the trees. We had not seen such forest soil since digging in the rain forests of Queensland's Atherton Tableland before the Second World War.

c) Enhancement options

This notable instance of soil making, which was repeated with other tree planting, could be considerably accelerated. For instance, it was done on poor soil-material, (subsoil and shale), without irrigation and with less than an abundant rainfall. The ripping for the rows of trees was 400 mm (16 inches) deep; it is quite practical nowadays to rip to 1,250 mm (50 inches) and more. The depth of chiselling between the rows did not exceed 200 mm (8 inches); it could likewise be ripped to 1,250 mm (50 inches) deep. Special plants would keep the earth aerated; many plants will go down to wherever the moisture is. No fungi spores were added; perhaps the best could be introduced. The earthworms arrived of their own accord; maybe the worlds largest earthworms from the Gippsland rain forests of Victoria could be introduced and would grow longer than their recorded 3,300 mm (11 feet). Very fortunately earthworms are not over-sensitive to the chemicals of industry and agriculture. To multiply these factors there is the effect of watering the city forest trees with the wonder-water from the city.

A great surplus of fertility could rapidly develop in the soil of a city's effluent irrigated forest. It would also physically increase by the addition of dusts from the atmosphere filtered by the leaves and washed to the surface by the rain. Other matter would be extracted from the effluent by the soil processes and by the trees themselves, to return to the soil in the leaf-fall. Although indeterminate at the moment, the surplus top soil fertility which would be available for sale to home gardeners, and for parks, gardens and plant nurseries would be big business.

E. A City Forest.

The wastewater from a city of 2,000,000 people could be profitably utilised on 8,000 hectares (20,000 acres) or even up to 16,000 hectares (40,000 acres). A large area? Perhaps, but certainly no giant in rain forests - or in grazing properties.

Even Sydney, a city of high priced land, has much larger areas in reserves and so-called parklands which are little seen and rarely used. True, much of it is apparently worthless sandstone shelf country. The ’water shape’ of this country is also poor. But the requirements of the rain forest are principally a place for the trees to stand up and adequate water.

1. Cultivating rock

Sandstone country can be cultivated, if not by rippers then certainly by explosives. We had experience of this kind of ’cultivation’ in 1951. A particular contract called for the removal of 20,000 thousand tons of sandstone daily which we lifted and dumped to the side with a dragline excavator - after ’cultivation’ with explosives. When each ’shot’ of a ton of explosives was fired, a nearby observer would hear only a dull whoosh and see the section of land lift en mass and settle back again. The surface was so little disturbed that motor vehicles could continue to travel on it. But no matter how heavy a deluge, no water ran off and none formed pools on the explosive-cultivated land. Incidentally this contract was planned in 1950, and designed to operate on these same principles of ’complete water control’ even if rainfall was extremely high. 1951 turned out to be the year of the “widespread big wet”. The nearly incessant rein eventually closed every coal mine, both underground and open-cut, in New South Wales, while our job did not lose a day.

The sandstone shelf country is frequently of ’poor water shape’ which means that the three shapes of land - main ridge, primary valley an primary ridge - are not smoothed over and made suitable for rapid irrigation with the minimum of rock-moving. A simpler method of constructing natural water shapes would be to use the garbage disposal which is in plentiful supply. Indeed the garbage disposal problem could be solved for centuries to come by using it to turn the rocky gorges of the sandstone shelf country into luxuriantly forested valleys with deep living soils.

2. Perfumed forests

The vanishing rain forests of Australia do not have the unpleasant smell of many tropical forests. For the City Forest even the perfume could be chosen by planting a few special trees.

The natural rain-forests, wherever they remain, have in common the great water absorption capacity to stop any amount of rain-fall in its tracks; to take in water very quickly and to release it slowly in springs of clear water. A region which is covered with good grassland soil does not produce heavy floods, but covered with deep forest soil, floods are not possible. Flood control is merely one coincidental of correct landscape design. There is another that would belong to the City Forests and it is even more significant; they would be fire proof.

XVI. CHANNELS: SOME OBSERVATIONS

Water has been transported from place to place by means of channels in the earth since time immemorial and it is still the cheapest method. But as previously stated, there are two prices to be paid for water, the second being the cost in water itself.

This second cost, water being lost in its transportation via channels, becomes continuously higher as the distance it travels becomes greater. The enormous loss of water from Government irrigation supply channels is a matter of continuous concern.

The solution to the problem of water lost by seepage and to a lesser extent by evaporation, is enormously costly. It could involve the concrete lining of hundreds of miles of main supply channels or, alternatively, the replacing of channels with huge pipelines.

There are no such problems with the use of channels for transporting farm waters around the farm. Here the channels are cheap to construct and they don't wastewater. There is practically no cost in wasted water because the distance the water travels is, by comparison, insignificant. Moreover its speed of travel is considerably faster than the slow movement of water in Government supply channels so that the ratio of seepage and evaporation loss, without regard to distance, could be a great deal less.

There are as well, further farm-favouring comparisons. For instance, when the largest farm channel, the diversion channel, is carrying its greatest flow of water it is sure to be raining heavily. Where then are the seepage and evaporation losses? On the other hand the Government supply channels are very large and carry their greatest flow in hot, dry weather when all farmers would like to irrigate their land. When a farm irrigation channel conducts farm stored water for irrigating, the water has been released directly into the channel at the quick turn of a tap, or pumped, and is spilled out from the channel to irrigate the land after travelling only 20 metres (22 yards) or maybe less than 6 metres (20 feet), while at the conclusion of irrigating the distance travelled by the water would scarcely have reached one kilometre (1,100 yards).

This same small sized channel, when used for reticulating the water of the Government irrigation scheme from farm to farm, is very long and the water travels slowly. In addition, seepage is a universal problem of the large irrigation area itself and has caused many problems of swamp creation, salting and water logging even to the serious stage where whole productive areas may be made entirely unproductive.

When the farmer is using his own developed, water resources no such problems exist. If there is a little seepage water, it will be only slightly less valuable than the controlled irrigation itself. In this and in every other phase of water use for agricultural purposes, no other set of general practises can approach the sheer efficiency for all available water, than the properly planned development and management of the farm’s own water resources.

A farmer can very clearly see that a channel for water control which is suitable for a certain piece of country, is a practical and simple sort of thing which does not in any manner overawe him with its likely cost or with its construction. Though it is a different matter when it comes to interpreting and visualising the same thing on his own land, or deciding on its size.

He can see for the first time an irrigation channel working in undulating country and irrigating quickly and economically and then may immediately determine that it would not work for him because his land looked very different. In truth his particular conditions may be even more favourable for exactly the same procedure.

Occasionally there is the reverse effect; a farmer whose land is very flat may see a large flow of water irrigating on undulating country and decide he must have it. He remembers that the channel fall is 1 in 300 and may select a spot for the start of an irrigation channel on his own land near a dam, or a natural water-hole from which he could pump the water. Of course, he finds when he starts taking sights with a level that there is not any 1 in 300 fall on his land at all, it is much too flat. If he persisted further in the attempts to transpose a technique completely out of its land shape setting, by excavating the channel as he had seen it, but now with the necessary very flat fall, he would soon find that the water would behave very differently. It would not be possible to get the water out of the channel, but would merely cause it to spill from the channel and from both sides of it, all over the place, which would likely create a swamp, but certainly not a valuable paddock of irrigation land.

It is not the purpose here to present all aspects of channel uses on farm and grazing land or to provide a working manual from which could be determined all the aspects of volumes of flow and related channel sizes, shapes and rates of fall. For the present, except where details are given of specific cases, these matters can be left until later.

There are many circumstances where those details can best be determined on the development property itself and if necessary, with the aid of engineering advice. It is the intention to illustrate here, the forms and practical uses of channels so that their general types and particular uses can be appreciated by the landsman where there is possible application for his own land. It is hoped there is sufficient information herein to assist land owners in the intelligent consideration of any advice which he may receive on these matters.

In water resource development of farm and grazing land, there are two principal uses for channels:

- Firstly; for the diversion of direct rainfall run-off, stream flow and pumped water, into a dam for storage.
- Secondly, for carrying water to a specific area for irrigating the land.

The various forms in both types of channel are dictated by the shape of the land through which they pass and by the volume of water flow which they are to carry.

A diversion channel used for collecting rainfall run-off from the steeper country to fill higher dams placed at the Keylines of the primary valleys, is a very different undertaking to that of a diversion channel in flatter areas.

A. Diversion Channels.

In the first case this channel on undulating land would consist of an earth bank and the channel against it from which the earth was taken. It would be constructed generally by a bulldozer equipped with an angle-and-tilt blade or by a power grader, side-casting the earth from the land immediately above to form the bank. It may be completed in from four through to ten side-casting runs. The rate of fall of the channel would be 1 in 300 and it may carry a flow of 4.5 Megalitre s (one million gallons) of water an hour. It would carry only a small part of its capacity in the excavated portion, the main part flowing against the earth bank. In total width from the lower edge of the bank to the upper edge of the cut, it may be only 4.5 metres (15 feet). In appearance and cross section it would be as below in the following image Plate 39 and Figure 33.

Plate 39 Early (1958) feeder channel constructed by bull dozer. Note parallel belt of timber left below the channel.

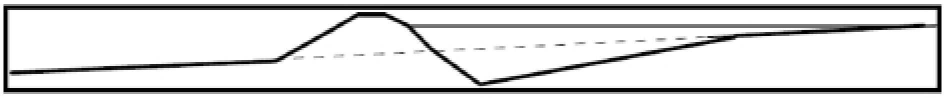


Figure 33 Cross section of a diversion channel in undulating country. Fall 1 in 300.

In the second case, a channel to carry a similar amount of water but in much flatter country, could be described in the same way, but a much greater number of side-casting runs would be necessary for its construction. Also its size and appearance would be very dissimilar.

According to circumstances, its rate of fall may be anything from 1 in 500 to 1 in 5,000. It would carry more of its water capacity in the excavation from which the bank was dug, but well over half of it would be held by the bank. It may be built by side-casting as before, but may require 32 or more side casting runs for it to be complete. More conventionally it would be constructed with the straight blade of a bulldozer working back and forth at right angles to the channel and from above it. The width would be from 12 - 18 metres (40 - 60 feet). The appearance and cross section are illustrated in figure 34 below. Bank height 0.7 m (28 inches) freeboard 0.1 m (4 inches). If the bed is not flat the lower side should be away from the placed bank. Right side in the following photograph Plate 40.

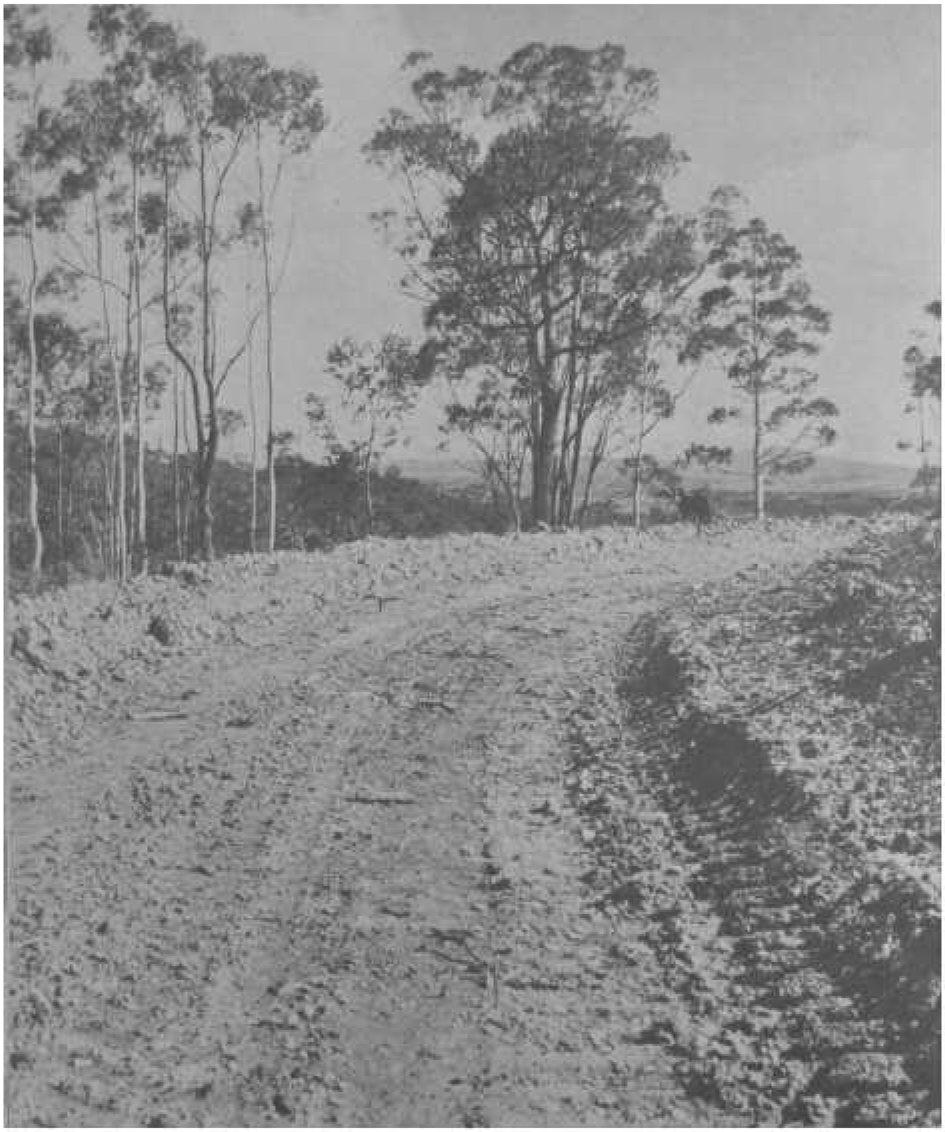


Plate 40 A diversion channel of several times the capacity than that on the previous page. The channel has a similar grade but is much longer. This type of channel is also suitable in steeper country and the associated farm road is in the bed of the channel rather than on natural surface on the lower side of the channel.

Figure 34 Cross section of a diversion channel in flatter country. Fall 1 in 500 to 1 in 5,000. Excavation cross section matches bank section. Flow rate when channel grade is 1 in 5,000 is 5.5 ML per hour (1.2 million imp gallons per hour).

B. Irrigation channels.

1. Keyline Pattern (hillside) Irrigation Channel

Keyline Pattern hillside irrigation uses excavated channels with no raised bank below the ditch. The width is 1,200 mm (48 inches), depth 600 mm (24 inches) and base width 600 mm (24 inches). It falls at the rate of 1 in 300 and has a water flow capacity of 2.2 Megalitre s (475,000 gallons) per hour.

Plate 41 Close-up fo an irrigation channel for Keyline Pattern (hillisde) Irrigation. The channel is 1.2 m (48 inches) wide, and has a fall of 1 in 300. Note the relationship of the channel to the pegged line.

The water is delivered directly into the channel from either a 300 mm (12 inch) or a 400 mm (16 inch) Lockpipe System from the storage dam. The larger size pipe is preferred for shallower dams with only 3 metres (10 feet) depth over the Lockpipe. A cross section is shown below in figure 36 whereas Figure 37 shows alternative cross sections.

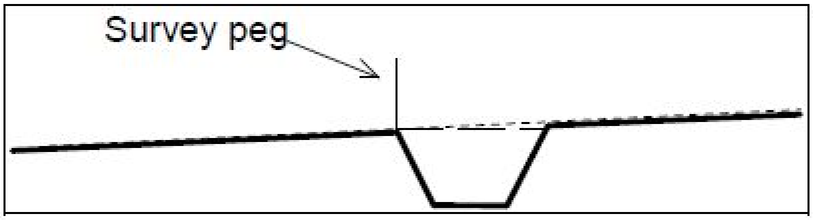


Figure 35 Preferred channel cross section for hillside (Keyline Pattern) irrigation. Grade is 1 in 300; with a range between 1 in 250 and 1 in 500. Note the channel is dug beside the surveyed peg on the uphill side so that the lower lip of the channel is on the surveyed line.

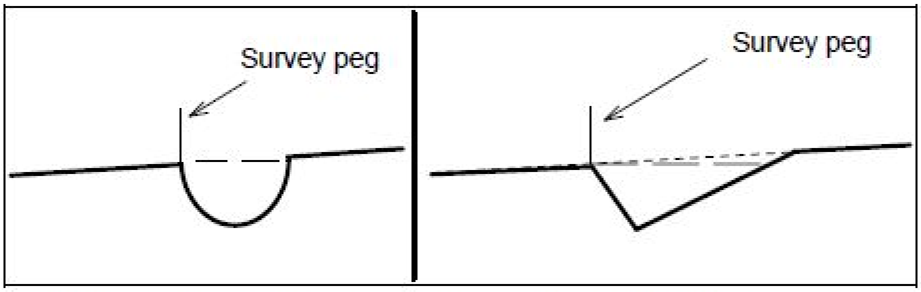


Figure 36 Alternative cross sections with similar flow capacity. One made with a rotary channel digger, the other with angled blade, which forms a flat V channel. Both are excavated 600 mm (2 feet deep). The channel width at the water line of semicircular section is 1.2 m (4 feet) whereas the V channel is 2 m (6 feet 8 inches). The wider channel is impractical for a person to straddle.

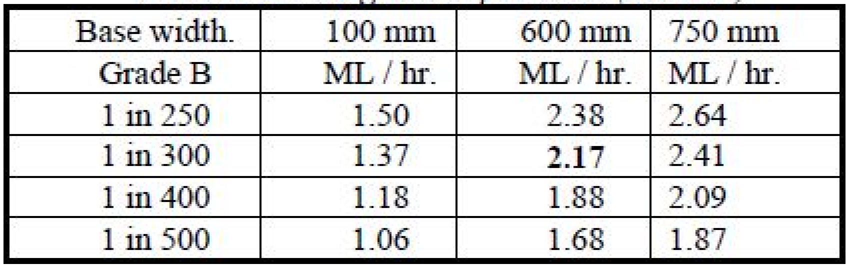
A smaller version of the channel cross section shown in figure 36 may be excavated with a three point linkage delver. A small farm grader is needed to dispose of the earth away from the sides of the excavated channel. The grader is used after each run with the delver to spread the excavated earth away from the channel edge. This prevents a build up of earth which alters the height of the lower lip of the channel and also may prevent the machine from getting to its correct depth.

The full size channel can be efficiently constructed using an excavator. The excavation cost of such a channel will be about $1.00 per linear metre. A specially constructed bucket can be used or a standard parallel sided bucket can have triangular wings attached to the side of it. The wings form the sloping sides of the channel. Many newer excavators can angle the bucket to trim the sides of the channel. The earth from the channel can be placed on the upper side of the channel. The placement of the excavated earth can effect run off water entering the channel so it should be flattened and spread so that it does not itself create a water holding bank above the irrigation channel. This excavated earth can be graded to form the road above the irrigation channel. Alternatively this excavated earth can also be used as a control bank to direct run off water into the irrigation channel at selected locations.

a) Irrigation channel grade and flow rate.

Altering the grade and base width has a significant effect of flow capacity. The following table assumes a constant top width of 1.2 metres.

Flow rate in Megalitre s per hour. (ML / hr.)



Base width.	100 mm	600 mm	750 mm
Grade B	ML / hr.	ML / hr.	ML / hr.
1 in 250	1.50	2.38	2.64
1 in 300	1.37	**2.17**	2.41
1 in 400	1.18	1.88	2.09
1 in 500	1.06	1.68	1.87

A Megalitre is a million litres or one thousand cubic metres. A Megalitre will cover an area of 1 ha to a depth of 100mm (4 inches) or 2 ha (5 acres) to a depth of 50 mm (2 inches).

It is critical in this type of channel that it's lower edge coincides with the accurately pegged falling line, therefore the excavation should be made just above this line.

During irrigation, the water flowing along in the channel is blocked with an "irrigation flag", which forms a channel dam or stop. The irrigation flag in its finished form is a 3 m x 3 m (10 feet by 10 feet) water proof sheet.

Through a hem on one edge is threaded a 100 mm (4 inch) diameter piece of light weight pipe (aluminium, PVC, bamboo, etc). Through a smaller hem on the opposite edge is threaded a 3.5 m (12 feet) length of chain which sinks the upstream edge of the flag down into the water. On each end of the chain is attached a steel spike (tent peg) about 250 mm long and about 5 mm in diameter. The spikes and chain stop the flag from inverting itself and releasing the water.

When the irrigation flag is in operation, the water builds up, on and against the flag till it spills over the lower lip of the channel, upstream from the flag. The length of the spill being perhaps 12 to 24 metres (40 to 80 feet). When the area below this flag is satisfactorily watered the flag is removed to release the water to flow onto the second flag. The first flag is replaced in the channel beyond of the second flag. A third irrigation flag is often used for convenience. Irrigation proceeds in this manner away from the dam to the end of the irrigation area.

A water stream such as this, when spilled onto a hill side, will naturally tend to come together and follow the steepest path quickly down to the valley below. Keyline pattern cultivation counters this and causes the flow to spread out into a wide sheet of water. The Keyline pattern of cultivation also ensures the penetration of the water into the soil by physically loosening the soil without inverting it. Uniform spreading of the irrigation water is achieved by the combination of flag positioning and the cultivation pattern.

2. Keyline Flood-flow irrigation of flat country

A dual bank irrigation channel for Keyline Flood-flow irrigation of flat country is shown in the following picture Plate 41 and the cross section in Figure 38. The channel is 18 metres (55 feet) wide and is constructed on a true contour, so it has no fall. The channel in the photo is flowing at 4.5 Megalitre s (one million gallons) of water per hour. It has a capacity of over 8 Megalitres (one and three quarter million imp gallons) per hour.

The pegged line for this channel is along the lower bank and the second bank is parallel above it. Each bank was laid in by sidecasting in two runs. The water is held by the banks and so it flows on the top of the land. Below this channel is a series of small earth banks which form irrigation bays each bay with an average area of about 4 hectares (10 acres). The flow of irrigation water, 4.5 Megalitres (1,000,0000 gallons) per hour, is released on to the land of each bay in turn.

The water is held by the banks so it flows on the top of the land. Below the channel are constructed a series of small earth banks which form irrigation bays. A suitable area size for each bay is about 4 hectares (10 acres) and the flow of irrigation water is released on to the land of each bay in turn.

Plate 42 Looking along the contour of a dual bank Flood-flow irrigation channel. The first test flow of 1.8 ML/hr in a channel designed to carry 9 ML per hour (2,000,000 imp gal/hour).

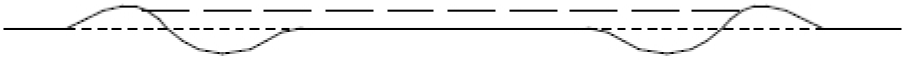


Figure 37 Cross section of a contour (no fall) irrigation channel in flat country for Flood-flow irrigation.

3. Comparison of system constraints.

In the first of these two types of irrigation channel, the excavated channel for use in undulating country is limited in its capacity, therefore its rate of irrigating land, by two factors. In the first place it is designed for one-man operation and as it is frequently necessary for the operator to step over the channel and on occasion even to straddle it, the width for human convenience has definite limits. In the second place it was is designed for low costing construction by farm equipment with only the general addition of the delver, therefore the drain size is again limited by this consideration.

Although it has not yet been done there is no apparent reason why the system could not be made with larger channels. The flags would be much larger and would be placed in position and released by a man on either side of the channel. This departure would be warranted in the very favourable circumstances where there existed an association of large-area primary ridges and a bigger capacity storage site in a nearby primary valley or where, from a large storage, a pump could lift the water economically to an irrigation channel set, for instance, not too much higher than the top water level of the storage.

Multiple channels fed by a larger Lockpipe system have already achieved an increase in the rate of irrigation. The objective of both these set-ups could be the irrigation of 30 to 40 hectares (80 to 100 acres) per day.

This channel and flag method of controlling irrigation water, while designed specifically for Keyline Pattern irrigation for pasture and grain, also lends itself ideally to cash crop and orchard furrow irrigation with only the obvious slight variations.

The limits to the rate of irrigation of flatter land with Flood-flow irrigation are not those imposed by operator considerations. Because the water-gates by which the water is controlled and released in irrigating are only increased in number and not in their size, the operator would not be taxed in controlling a 9,000 m^3 (9 ML) per hour (two million gallon per hour) flow instead of only half this flow rate. The limitations are the obvious ones of water supply, the delivery channel and the availability of a sufficiently large area of uniform and gently falling land.

Because earth channels are the lowest costing means of transporting water it follows that in the water resources development of the of farm and grazing land and in the direct irrigation from these water resources, the appropriate channels must play a major role. It is of great importance also that the sites and positions for the various types of channel should be located according to the dictates of good design, since channels may play the dominating role in planning for the maximum development of agricultural land.

XVII. THE FLOOD - FLOW IRRIGATION CHANNEL

The term flatter lands, signifies all land having fairly uniform slopes with a fall of from 1 in 30 to 1 in 10,000 or even flatter. It is to be noted that the cut-off point in the classification of undulating land and flat land can not always be precisely determined and direct experience on a particular property with borderline slopes may be necessary to determine the choice between methods of irrigating the land.

While Flood-flow irrigation itself is suitable for such wide slope ranges, it becomes necessary to employ two distinct types of irrigation channel for the transport of the irrigation water to cover this full range of slopes.

On the steeper of these flat land slopes of from 1 in 30 to say 1 in 100, the irrigation channel is formed by a single earth bank not less than approximately 60 cm. (two feet) high, which is constructed across the general fall of the land. The irrigation water then flows on the land on the upper side of the bank. The width of the irrigation stream will thus vary according to the volume of flow and local slope variations of the land immediately above the irrigation channel bank throughout its length. Thus an irrigation stream of constant flow volume could vary in some circumstances from 6 to 50 metres (20 to 165 feet) wide.

On lands where the slopes are flatter, the irrigation channel is formed by two such earth banks being constructed in parallel form across the fall of the land. The irrigation water then flows on the surface of the land between the parallel banks. The distance that the banks which form this irrigation channel should be apart will depend on the flow volume of the irrigation stream. The banks themselves may remain the same size, for irrigation stream flows that vary from 2.25 ML / hour to over 9 ML / hour (one half to two or more million gallons per hour). The channel varies only in the distance the two banks are apart.

Plate 43 A Main Flood-flow irrigation channel under construction. The dam can be glimpsed in the background.

Plate 44 Aerial view of a flood flow layout near Hughenden Qld. It is more practical to split a widening bay by starting a new steering bank well down from the channel rather than have long narrow bays as shown here. The starting point for that bank is selected to appropriately divide the flow of water.

It is especially noted with both these types of irrigation channels for the Flood-flow system, that (1) the water flows almost entirely on and above the land level, (2) the width of the elevated channel is much wider than the irrigation channels for other flow systems, and (3) the irrigation water of the Flood-flow channel, being on and above the land level of the land, is available for rapid release into the irrigation bays most economically.

A. Marking out the irrigation channel

The starting point of the irrigation channel is at the delivery point of the irrigation water. This delivery point may be:

(1) at a lock-pipe valve which releases water through the base of the wall of a storage dam, pond or lake, or

(2) at the water-gates which release the top thirty to sixty centimetres (one to two feet) of water from a storage dam, or

(3) at the delivery or discharge outlet of a pump, or

(4) at the point where a diverted stream arrives on the area to be irrigated.

The general level point or datum for pegging the levels for the Flood Flow irrigation channel line uses the invert (bottom) of the lock-pipe outlet pipe, pump discharge pipe, or to the horizontal channel frame (sill) of the water-gates. Water gates are occasionally used to release the top water off a storage.

The starting level of an irrigation channel which is to receive the water from a lock-pipe below the wall of a dam or from the outlet pipe of a pump, can be taken directly from the invert of the pipe outlet, or below this level by about 0.3 metres (a foot). In both these cases, the water which

flows into the channel is forced out by positive head or pressure. The flow into the irrigation channel from a lock-pipe beneath the wall of a dam has a pressure head produced by the depth of water in the dam which is above the outlet. Thus a depth of water of 6 metres (20 feet) above the outlet, produces a water pressure of 6.0 kPa (8 pounds per square inch as a head of one foot equals approximately 0.4 pounds per square inch) and a depth of 2.4 metres (eight feet) above the outlet produces a pressure of 2.4 kPa (3.2 pounds per square inch). The flow from a pump will also have a positive pressure.

In both these circumstances, and for the same reason, it is permissible to have the irrigation channel at such an elevation, relative to the pipe, that water can build up and partly or even fully submerge the pipe outlet. The loss of flow will be small. But this does not apply to the release of water through water-gates from the top of a filled dam. If the position of the irrigation channel is such that water soon builds up against the flow through the water-gate, then the flow is impeded and greatly reduced.

One Keyline development overseas includes a sizeable Flood-flow irrigation project. The irrigation channel was sited on a level 0.4 m (16 inches) below the level of the sills of the water-gates. These water-gates were designed to release the topmost 0.4 metres (sixteen inches) of the dam waters. The dam itself being kept in a fully filled condition by the water from a constantly flowing stream that had been diverted for this purpose. The designed flow of a million gallons per hour, for the first stage of the project, was maintained through two by 1.8 metres (six feet) wide water-gates. The diverted stream, which was itself fully controlled by a water-gate at the stream source some distance away, continued to flow into the dam during the irrigation. With its large surface area, the dam lowered only a few centimetres (few inches) during the irrigation of 80 ha (200 acres) of pasture. The top water level at the commencement of each irrigation, being 0.4 metres (sixteen inches) above the sills of the water-gates, was thus 0.8 metres (32 inches) above the ground level of the irrigation channel to which the water flowed. The level point at the start of the irrigation channel can be lower than indicated and this could only improve the water flow position. However, it is usually desirable to have the irrigation stream as high up on the land as is practical for flow purposes.

On the other hand, the pressure water from lock-pipe or pump flow may on occasion be raised a foot. This would involve higher banks on the irrigation channel for a portion of the length at the end near the water inlet and the creation of a pond area to raise the water level the extra foot to cause it to flow along the channel. Such a design feature does however reduce the amount of water available from a dam as it empties. The amount is the water in the dam representing the extra height. Again in the circumstances where there is more water than required to irrigate the available land which is below, then the extra 0.3 m (foot) of height is very valuable in that it substantially increases the area of irrigable land. For instance, where the land has a general slope of 1 in 2,000, the extra 0.3 m (foot) adds a strip of land for irrigation 600 metres (2,000 feet) wide and for the full length of the irrigation channel.

However, with the starting level point decided, a peg is driven in to mark it while another reference level, at the same height, is marked and permanently pegged some distance away where it will not be disturbed or lost.

1. Pegs

It is of considerable advantage to use good pegs, which should be of a height suitable for the surroundings and which have been painted for easy location and sighting. It has been found that tomato stakes of 25 mm (one inch) square timber 1.8 metre (6 feet) long make suitable pegs. The stakes are cut in two, or in three pieces if the grass is short, and the top 75 mm (three inches) painted with white paint. The use of 1,200 mm by 6 mm diameter steel rods is an alternative to timber, providing pegs that have few shortcomings and many advantages. The rods being less bulky are easier to carry, sometimes less expensive, easier to drive into hard or rocky ground and not susceptible to white ants or fire. Fibre-glass rods of similar dimensions to the steel rods are also readily available. They are commonly used for electric fence posts. They have the advantage of great flexibility and being white are some what easier to see initially. These pegs can be driven into the ground with a simple rammer made from a 750 mm (3 feet) length of 12 mm (half inch) water pipe. One end is simply blocked by a screwed on cap. It is an advantage to fit a bit of leather or a tap washer inside the cap to act as a pad to stop the fibreglass from shattering. Old used fibreglass rods are notorious for hurting the hands with fine fibreglass splinters, so take care. All pegs are easier to see with some flagging tape tied to the top. The best colours are fluorescent pink and orange.

2. Levels

One of several different types of levelling instruments can generally be used to level-in the irrigation channel line. They are the engineer’s automatic level, a laser beam level and the transparenthose water level. The automatic level is by far the most commonly used and is relatively affordable, although high powered laser levels are used by some government department.

The Yeomans designed Bunyip level[16] of the third type, consists of a 60-feet length of half-inch transparent hose with five feet of each end fitted into two specially shaped metal staffs which are graduated in feet and inches to a sixteenth of an inch. It was never produced in a metric version. Each end of the hose is fitted with control buttons which, when in operation, are pressed to allow air into the hose. The hose is filled with water to within a foot or so of each end.

In operation, one staff is set up at the starting level point by one operator, while a second operator selects his trial position a hose length of 15 metres (50 feet) away. Each operator then presses his “atmosphere” button which allows air to enter and permits the water in the hose to find its own level. The water level is then read on each staff. Operators can become quite expert in the use of the Bunyip level with only a few minutes experience. “Simple Surveying for Farmers” by Professor Frank Debenham, describes the full usage of the Bunyip level including its use for do-it-yourself farm surveying and contour map production. Levels of similar type, but which include a hose of opaque material should not be used, since with them it is impossible to be sure that there are no air bubbles in the hose. At worst, the presence of large air bubbles make any work done quite useless, and, at best, produce slow readings which are still of doubtful accuracy.

If levelling work is necessary, then it must be accurate and the farmer should have sufficient knowledge and experience with the level he uses to be confident that his work is accurate.

3. Channel Gradients.

The Flood-flow irrigation channel may have a fall or be quite flat, according to the particular circumstances. For instance, in very flat country of 1 in 2,000 to 1 in 10,000 slope, only a contour and twinbank irrigation channel will serve, whilst on land with a general average slope of 1 in 100, a single bank irrigation channel with a fall of only 1 in 5,000 has been found to be more than steep enough.

A contour channel is often preferable. The disadvantage of a falling channel lies in the fact that too much of the flowing water could by-pass the open water-gates and, after reaching the furthermost end of the channel, the water could build up sufficient height to overflow the bank. In the case of a 1 in 5,000 channel that is 1,600 m (a mile) long the difference in height from one end to the other would be 0.32 m (12 inches). It may become necessary in such circumstances, to place earth stops equipped with water-gates across the channel itself to prevent this from happening and to direct the water into the irrigation bays. Such cross channel stops may reduce the cross section of the channel and it may prove impractical to provide the same total cross section in water-gates as the normal channel at each of these cross channel stops. There will be circumstances where it would be better to build the channel in a stepped form so that the last water-gates would discharge into a slightly lower channel that is also on a true contour.

These measures may be unnecessary in irrigation channels built on the true contour, and in those circumstances where cross channel stops would be an advantage, fewer stops would need to be placed at much longer intervals apart, along the channel.

Considering these matters from all points of view, it becomes obvious that the lower the flow volume of water, the more necessary becomes the need for a fall in a channel and the more positive should the fall be as the flow volume decreases. Conversely, the greater the volume of flow, the more it is confined by banks and the deeper it becomes in the channel, the less is the need for a fall.

As Keyline Flood-flow irrigation employs much larger flows than any other irrigation system, there is no need here to consider lesser flows and their channel falls. Therefore, a perfectly level or contour irrigation channel becomes the general type.

It may at first be thought that water will not flow in a channel on the true contour and with small flows this may sometimes be correct. But when the big flow of water is discharged into the closed and banked-up end of a Flood-flow irrigation channel there is nowhere that the water can go, except to immediately build up depth and thus create its own positive down-slope and flow along the contour channel.

So, in the levelling in of the irrigation channel, a contour line is customary and also, when there is any doubt as to whether or not a fall should be given to the channel, then a contour line should be pegged for observations that will assist in making a decision on the matter.

Those who own an engineer’s dumpy or automatic level probably know how to use it. Those who do not should still preferably do their own levelling work, but with a water level as previously described, if necessary.

Generally a true contour line should be pegged at each 15 metre (50 foot) interval. This distance is automatic and more than sufficiently accurate when the slack hose of the Bunyip level is used as a measure.

In pegging the line for the irrigation channel with a Bunyip level this instrument is first checked to see (1) that with the two staffs of the Bunyip standing upright and together the transparent hose is filled with water to within a foot of the ends of the hose in the staffs, (2) that there are no air bubbles in the length of the hose, (3) that when the atmosphere buttons or valves are both opened and one staff lifted 150 mm (six inches) or so, the water in the hose moves freely or bounces, and (4) that this bouncing of the water ceases when the atmosphere buttons are again closed. The level is then in operating order.

One operator should place the foot of his staff against the starting peg on its upper side as the second operator selects a trial spot for the next position by walking the full length of the slack hose, 15 metres (50 feet) away. Then with the two staffs upright, both atmosphere buttons should be pressed in and each operator call the water level reading on his staff. If the second operator’s reading is the greater, then his place is low and he changes his position in the direction of the rise of the country, again calling the staff readings until both are the same. If on the other hand the second operator’s staff reading is less than the first, his position is too high and should be adjusted accordingly. In this manner, the exact site for the second peg is determined which is pushed into the ground against the staff on its lower side.

To fix the position of the third and all subsequent pegs, one of two operator-movements may be followed. (A) Both operators move together, number one to the position vacated by number two, where he places his staff in the exact position previously occupied by number two (staff against the peg and on the higher side) and number two operator moves to a point he selects as a trial for the position of the third peg, which he then locates in the same manner as he did for the second peg. (B) Number two operator maintains his staff position as number one walks with his staff past him and selects a trial position for the third peg which is then located the same way as the second peg.

The line is thus levelled in and pegged to some obvious limit, such as the point of change from flat to undulating country, a definite stream or water course or a boundary, or to a suitable distance point such as one half, one or more kilometres (miles) away.

It is to be particularly noted that the larger the flow volume of water under control, the greater the distance the water can flow efficiently in the irrigation channel. Moreover, as already stated, the cost of constructing the irrigation channel does not increase with the greater width necessary for an increased flow.

4. The form of the line for the irrigation channel.

The line thus pegged may be fairly straight and even, which will indicate that the form of the land is large. The line may be in the shape of one large uniform curve indicating either a large but very flat valley formation or a large flat ridge formation. Again the line may have uniform curves swinging alternately towards the rise of the country and away from it, which indicates alternate flat valley and ridge formations.

The pegged line may be in any of these forms but be far from smooth or uniform. As a channel of smooth and regular line is desirable for construction purposes and for the practical management of the irrigation area, the last-mentioned line is adjusted or normalised. This is done by walking-the-line and examining the outof-line peg positions for an alternate site which would improve the line form.

It must be remembered, that the present shape and form of most of the flatter land has been stabilised as a result of its vegetation, rainfall, winds and flowing water of past ages. While these land shapes then do have some variety, they all tend to produce smooth curves in their contour lines. Where a badly shaped line results from the contour level pegging, it is often the result of some form of soil deterioration. For instance, vast areas of flat land which have suffered from recent wind erosion caused by unsuitable stock management practises, or a series of drier than average seasons with high winds. These conditions may have produced local variations in surface levels of around 10 cm (several inches) in a distance of only 15 metres (fifty feet), in circumstances where the general fall of the land may be only 1 in 5,000 (twelve inches in a mile). In these awkward conditions, the level operators should try to follow the remaining spots or areas of original surface or, if this is impractical, they should avoid all noticeably high and low spots. The high spot to avoid will usually be associated with scrub plants where windblown dust has been deposited, the low spot being between bushes. The greater the extension in length of the contour line from the starting point, the more the true contour of the original surface discloses itself which is the line required for the construction of the irrigation channel banks.

So in walking the pegged line for the purpose of normalising adjustments, it is advisable to carry pegs of a distinctive colour. Then, when an original peg appears out of the general pattern of the line, the spot is examined to see whether, because it is on a local high or low spot, it can be moved up or down the land respectively to improve the line. The old peg can be left momentarily and a new peg of different colour placed in a better line position. A better and smoother shaped line can thus be produced and still remain, for all practical purposes, on the true contour. We have called this action of adjusting the line “normalising”.

5. The Rule for Normalising a surveyed line.

“High can go higher and low can go lower”. A peg on a localised high spot can be moved higher up land to a spot if it improves the over all shape of the line. A peg on a localised low spot can be moved lower to another spot if it improves the line. Common sense should be used to limit the correction to that which is produced by the localised anomaly in the height at the peg.

Although it is important that the general aspect of the line is that of a contour, it has been found from experience, that purely local small variations in level matter little and even less as larger flows are used. Nevertheless, on generally uniform land, it has also been found that a small adjustment to the position of a few individual pegs will always improve the uniformity of the curves, thus enhancing the overall appearance of the final channel. “Normalising” of a line does not aim to produce a straight line for an irrigation channel where the contours indicate curving forms.

However, no adjustment should be made to improve the line during the actual levelling-in of the line, other than by avoiding the local high and low spots. This levelling and pegging should always be completed first so that the true line is more readily disclosed by the pegs which have been accurately placed with the levelling instrument.

If the irrigation channel is of the single bank type, this levelled line completes the pegging for the irrigation channel. If the channel is of the twin-bank form, then the second bank is pegged by measurement only above this first line of pegs. From each peg of this line the set distance is measured at right angles above it and the new pegs are placed through to the end of the line. The distance the two banks should be apart is determined by the factors already mentioned. In general, the channel should carry its full flow of water with less than 0.3 metres (12 inches) depth of water against the single bank, or against the lower of the twin banks.

B. Constructing the Flood-flow irrigation channel

It is an advantage to have a clean line with which to work. Unless the grass is short it should be cleanly mowed for about 2 - 2.4 metres (seven or eight feet) above and below the pegged line and the cut grass moved away from the line.

A strip of land 2.4 metres (eight feet) wide extending from the levelled-in and pegged lines on both sides should be cultivated two or three times with a chisel plough or sub-soiling ripper. The course of the cultivation should match-in with the pegs in such a way that smooth curves are formed rather than a series of short straights from peg to peg. The objects of the cultivation are twofold: Firstly, to ensure that the new earth bank will bond into the earth below it, and secondly, by cultivating each time with the chisels in the furrows of the first run, guide lines are provided to help the operations of the side-casting implement in the forming of each bank. If possible the bank should be constructed while there is obvious moisture present in the earth. (Refer to the cross sections in figure 39 below of single and twin bank channels.)

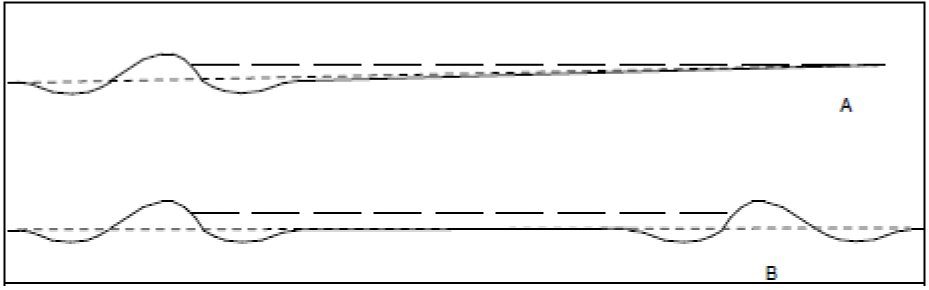


Figure 38 Cross section of contour irrigation channels in flat country for Flood-flow irrigation.

The first side-casting run is made with the lower and rear point of the blade of an angle and tilt bulldozer or grader, digging 0.9 metres (three feet) from the pegs, and throwing the earth away from the tractor but toward the pegs. The pegs may at this time be recovered for later use. The earth placed by the first run, is consolidated by running the tractor along the line with one track of the tractor on top of the loosely placed moist earth bank. The second side-casting run is similarly done, but on the opposite side of the line again throwing the earth on to the pegged line. Each side-casting run should be continuous for the full length of the line.

The side-casting implement should be operated at a good fast walking speed so as to obtain a suitable “throw” effect to the earth. While low gear of a crawler tractor is too slow, second gear operation at full throttle is usually quite effective. A tandem drive grader or an angle-and-tilt bulldozer of medium horsepower, are the most suitable machines for the construction of the banks of the irrigation channel.

After every side-casting run, the earth of the bank is consolidated by running the tractor along the newly placed earth with one track on the top of the bank. Two or four side-casting runs are needed with this type of equipment throwing the earth from each side alternately. When completed, a full sized bank should be about 1.8 metres (six feet) wide at the base and 0.6 metres (two feet) high.

During the construction of the bank, the earth immediately along each side is taken, which leaves depressions in the form of excavated drains. These drains may be stopped with small earth banks about 15 metres (50 feet) apart. They will be gradually filled and levelled off in the management and improvement of all the land of the irrigation area. The cultivation, sowing, eating out and occasional mowing and harrowing of the irrigated land includes, of course, the land of the irrigation channel which soon is fully grassed and stabilised.

In conditions which are hot and windy, it is desirable to adopt special measures to quickly grass the irrigation channel banks. By placing earth stops in the excavated drains beside the bank, ponds of water will lie along the sides of the bank after each irrigation, and these ponds will greatly assist the spread of grass over the bank by keeping the adjacent soil moist for some time after each irrigation.

In dry conditions, if water is available, may be released into the channel when the bank of the irrigation channel completed. This first flow of water may serve as a partial check on the work and will also provide suitable soil moisture conditions for the later completion of the work. If the banks must be completed with the soil very dry then it may be better not to attempt to consolidate them but await natural settlement which will occur after rain has fallen.

C. Water-gates

The construction of the bank or banks which form the irrigation channel are completed as described, namely in long fairly fast sidecasting runs which produce uniform banks. Now these banks are to be broken at intervals to provide outlets for the irrigation water into the individual irrigation bays. This is done for the installation of water-gates in the single bank channel and in the lower bank of the twin-bank channel.

Plate 45 A front end loader is used to remove a section of a Flood-flow irrigation channel's bank for the installation of a water gate.

Plate 46 Checking the level of the cut through the bank prior to installing the watergate.

It has been found that the most practical size for the water-gates is 1.8 metres (six feet) wide by 0.6 metres (two feet) high. There are two parts to a water-gate: (1) a frame in channel iron from which has a continuous fin projecting outward from the bottom and both ends and (2) a separate closing panel formed of sheet steel. The closing panel slides in the channel form of the gate frame and an effective water seal is obtained with a strip of sponge rubber which is attached around the contact edges of the closing panel.

The openings in the channel bank for the water gates can be made, by using either construction equipment, a farm tractor-attached front end loader, grader blade or hand shovel, but whichever way is chosen the work will need to be finished off by hand. The earth, from the openings made in the bank, is placed in heaps on the undisturbed bank at each end of the water gateway.

Plate 47 A newly positioned 1.2 m (4 feet) wide water gate supported by "star" steel posts. The opening panel slides in a slot formed by angle iron welded to the sheet steel.

The bottom and end fins of the frame are imbedded into the earth after digging a narrow trench to take the fins. If the earth is moist and soft it is often possible to set the gates without actually excavating the small trench. On one such occasion, an old meat cleaver was hammered into the earth to form a continuous slit of appropriate length and depth and the water-gate's fins-were then tapped into the slit. After placing the water-gates, the earth should be rammed into a tight contact with the fins on both sides. A 25 mm (one inch) round or square rod is very suitable as a rammer.

Whatever method is used to place the water-gates it is essential that: (1) they be placed in sequence from the commencement of the irrigation channel, (2) each water-gate, as placed should be levelled in from the previously placed gate commencing from the supply end of the channel. Where the channel is dead level the sills of all watergates will likewise follow the same level and where the channel has a fall, each successive water-gate will have the same rate of fall according to the distance the gates are apart. (3) The sill of the first gate must be on the same level as that of the datum of the channel, (4) the sills must be perfectly level, (5) the earth around the fins should be well rammed into a tight contact, and (6) the earth from the watergate outlet in the irrigation channel banks should be placed as tidy heaps on the bank at each end of the openings.

Plate 48 The leading edge of water coming along the main channel towards the irrigation area.

It has been determined from experience that one such water-gate will release irrigation water at up to the rate of 2.25 Megalitre s (half a million gallons) per hour and not produce any difficulties for oneman control or cause any soil to be wash away.

If a flow of water of much over half a million gallons an hour has only one water-gate outlet, then the level of the flowing water in the channel will rise to such a height that the increased depth of flow through the water-gate will eventually accommodate the full flow. There is a limit to this depth of flow. It is the height of the other closed water-gates. Half a metre (twenty inches) is the maximum of the closing control of the standard water-gate.

Plate 49 First flow into an irrigation bay. Without ripping most of the water would run off but here the water quickly pours into the loosened soil.

In practice, a water level of 30 centimetres (12 inches) at the water-gate should be considered as the crest which is both practical and economic. A greater flow from a water-gate can produce two problems: (1) It increases water flow velocity on the soil adjacent to the gate and immediately inside the irrigation bay; this is the one critical velocity point in the whole of the layout for the Keyline Flood-flow irrigation system. (2) It imposes an added depth of water against the irrigation channel bank.

In this regard it should be noted that the technique of side-casting for the laying in of the earth for the irrigation channel bank, while being very economical, has definite limits as to the height to which the earth can be placed. An extra 50 mm (two or so inches) of height to the bank involves a disproportionate amount of work.

Although the suggested constructed height of the bank is 0.6 metres (two feet), it will always flatten somewhat during the use and management of the irrigation area, so the banks lose some of their effective height. However, the chief consideration must remain one of flow velocity at the water-gate entrance to the irrigation bay.

The velocity of flow exiting the watergates is only exceeded by the velocity at the Lockpipe outlet. The width of the irrigation channel is such that even when recently chiselled, the velocity of flow in the channel with slight or nil fall is so slow, that wash does not occur. Likewise, the width of irrigation bays may vary from 2 to five or more times the width of the irrigation channel so that, even with a fall, no wash is likely to occur. However, where an irrigation channel for example, 18 metres (sixty feet) wide, supplies irrigation water at a rate of 4.5 Megalitre s per hour (one million gallons an hour) to each irrigation bay of 45 metres (150 feet) or more wide, it may do so through two water-gates with a combined effective width of 3.6 metres (a little under twelve feet). This will produce a speed of flow of 1.15 metres / second (3.8 feet / sec) if the flow is 0.3 metres (one foot) deep. Doubling the supply rate will increase the speed and depth of the flow through the gates.

The increased velocity of flow which occurs in each bay immediately at the water's entrance may not have any detrimental effect on a sward of pasture established at this point, but, as the water flows over some recently disturbed earth during the first irrigations of a new area, definite proceedings to stabilise these points in each irrigation bay may be necessary at times.

It has been found that the most practical procedure is to start the first full irrigation as soon as possible and use the water-gates with a full flow of water. One or two operators with shovels should constantly patrol the irrigation channel area to adjust any low spots or leaks that may occur in the banks. Every effort should be made to maintain the maximum flow of water so that a full test of all work can be completed. Pegs can be placed if need be to identify particular places for later adjustment. All water-gates should be used to their full capacity without any regard to possible wash. Moreover, the water flowing through the water-gates may be cloudy on the first use and any wash which may occur will not be immediately visible through the water.

On the day following the first irrigation test flow, the areas near all water-gates should be inspected and where wash spots are found they should be repaired using the earth which was previously heaped up on the bank at each end of each water-gate for this purpose. The repaired spots should be planted with grass seeds, and fertilised if appropriate, and firmed down by stamping. As all water-gates are opened the day following the completion of each irrigation, these spots should be therefore constantly under observation.

The cost of the water-gates on a 4.5 ML (one million gallons) an hour project may be $75 - $125 per hectare ($30 - $50 per acre) of irrigated land. On a particular project this cost may provide for irrigation bays with an average area of 4 ha (ten acres), with each bay being serviced by two water-gates. The time of flow to each bay would be approximately thirty minutes and the average water intake by the soil, under the conditions of good management, should be about 0.55 ML per hectare (50,000 gallons per acre) at each irrigation, which is an application of 55 mm (2.2 inches) of water. If both the flow rate and the bay size are doubled, the cost of the watergates per unit of area remains the same, although the labour cost, now extremely low, is halved.

In conditions of extremely unstable soil, an extra water-gate can be installed temporarily to each bay then taken out after the soil has improved and become more stable, then the gate can be used for later irrigation developments.

Water-gates, for a purpose other than the release of irrigation water, will be required on some Flood-flow irrigation projects where the twin banks irrigation channel is in use. In circumstances where rain-fall run-off would pond against the upper bank, water-gates should be installed and opened after each irrigation so that this runoff will move into the irrigation channel. Then, with the water-gates open from the irrigation channel into all bays, the rain fall run-off is distributed uniformly over the whole of the area. The comparative number of these gates in the upper channel to those in the lower channel is not determinable for all rainfall conditions, moreover the volume of run-off will also depend on the area above the channel which will produce the flow. One water-gate in the upper bank to each four in the lower bank is therefore given as a general recommendation only.

From this description of the design and construction of the channels for Flood-flow irrigation on flatter lands, it will now be apparent that this specially designed channel has outstanding advantages over the orthodox flat land water channel. Firstly, there is the more economical use of earth with the attendant lower cost, because the water in the usual channel flows principally along the earth which has been excavated for this purpose. The water flows on the surface of the land in the Flood-flow channel needing only sufficient earth to hold it there. For an equally large flow of water, its cost could be less than one-tenth an orthodox channel. Secondly, because the water flows on and above the surface of the land, it is most suitably placed for release into the large irrigation bays by the simplest and most economical means. Thirdly, the relatively small banks do not require cross-over bridges, nor constitute any obstruction to stock movement. The passage of vehicles across the small banks is a simple way of flattening the banks at suitable places.

There are further advantages in management, since the area of the Flood-flow irrigation channel itself is far from wasted, but instead is part of the irrigation land. It may be sown to pasture and grazed, harrowed and mowed with the rest of the area.

It is worth emphasising that the total land preparation costs for Flood Flow irrigation (including the formation of the irrigation bays by the water steering banks, which are discussed in the next chapter), are even less per unit area than the low cost of the water-gates.

XVIII. THE FLOOD-FLOW STEERING BANKS

- Irrigation bays descend from the irrigation channel along the maximum fall of the land.
- All water-gates are opened the day following irrigation and remain open until the commencement of the next irrigation.

These two factors, in conjunction with the correct width of both the irrigation channel and the irrigation bays in relation to the volume of the irrigation stream, provide in advance for some of the major requirements of good irrigated land management. These management requirements involve control of the soil's water intake so as to prevent excess watering. This is achieved in the design which balances the width and the length of the irrigation bays with the volume of flow, so the irrigation water remains in contact with the soil of the bays for only half an hour. This length of time can be halved to fifteen minutes with no disadvantage on all soils on which Keyline principles of management have been applied. Even an occasional doubling of this time to one hour will not have any substantially detrimental effect, except to wastewater, particularly when the soil is light and sandy and the project new. It should be noted that the smaller the irrigation stream in relation to the bay size, the longer is the water in contact with the soil and the greater is the chance of over-watering and making the soil waterlogged.

Destruction of soil by excess water and poor drainage has been, unfortunately, part of the history of irrigation for thousands of years. Therefore, it becomes necessary to make provision for good drainage. This is ensured in the first place, by the increasing soil fertility produced by Keyline soil management techniques and in the second place, by the fact that the steering banks which form the sides of the irrigation bays follow the steepest path down the land and therefore the most efficient surface drainage lines.

The location of the Flood-flow irrigation channel, the steering banks and the associated bays, with their combined but confined spreading effect produce the greatest benefit from rainfall and at the same time provide the best surface drainage pattern.

Plate 50 A small Flood-flow project in the Brisbane Valley, Queensland. Irrigating selected bays keeps the cattle on dry ground. The water is flowing to the right and remains visible in this area for about half an hour. This is the irrigation area seen in the distance of Plate 23.

In many circumstances, the Keyline Flood-flow layout would still be worthwhile doing on land that could not be irrigated, solely for the benefits to be gained from the control and even spreading of the water from run-off rain fall.

It is considered of particular importance that the design and layout of land for any type of irrigation should be such that the water from occasional, heavy and continuing rain immediately following an irrigation, is handled effectively and automatically and without damage to the soil. Hence the importance of having water-gates opened after each irrigation is completed when there is any chance of rain. Stated briefly, “good irrigation layout is automatically good drainage layout”.

However, these critically important factors are only rarely achieved by haphazard methods. For a start the naked eye cannot determine the “maximum fall of the land” on relatively flat country. In fact the unaided eye cannot with certainty, determine uphill from downhill on moderately flat land unless there is a visible stream or water-course to guide it.

The “maximum fall of the land” is one of these extremely important “water lines” and a levelling instrument is needed to determine the fall or at least “guide the eye”. But there is another point to mention before proceeding further. Eventually there could be more intimate subdivision of the irrigation land into suitably sized paddocks. Then fencing will be required other than that which divides the new irrigation land from the adjacent rain-pasture and crop land. Of necessity, one or more fences will cross the irrigation land downward from the irrigation channel, so consideration needs to be given to the general pattern of subdivision fencing when positions of the steering banks are being determined.

Suppose an irrigation channel 2,000 m (2,200 yards) long supplies an area 1,000 m (1,100 yards) deep, this area of 200 Ha (500 acres) will certainly need dividing in two and even four or more paddocks. The subdivision fences should not “fight the water” by crossing the bays on an angle, but should obviously “go with the water”. This fencing is therefore associated with the steering bank pattern. A fence should follow the steering bank which, first of all, suitably divides the area in two. It is a simple matter to do this but even so, a starting point for the fence must first be selected.

Although there may not be any critical factor relating to the selection of a starting point for the steering bank and its associated fence along the irrigation channel, there could be an exact position where a fence should finish at the lower boundary of the irrigation land. This boundary is sometimes a stream which may be suitable for stock watering. By locating the starting point of the first steering bank and its associated subdivision fence at this lower boundary, a selection may be possible which would provide water for the both paddocks instead of only one of them.

The finishing point in the locating of a steering bank is not at all obvious from a selected starting point. Consequently a starting point, if selected on the irrigation channel boundary, would not “come out” at the desired point in respect to say stock water facilities which may exist on the lower boundary of the irrigation area.

Steering banks are located by a levelling instrument, not by eye. If there are no such considerations as above to effect the placing of starting point, it may not matter whether the first steering bank is levelled-in from the upper or the lower boundary. Levelling-in upwards and downwards on flatter lands are in the nature of reverse proceedings, but this is not always so when there are even slight undulations to the land. For instance, to find the exact position of the steepest path in a valley shape, the levelling must proceed downward, whereas to find the exact centre fall of a ridge shape the levelling must proceed upward.

A. Locating steering banks

There are two basic procedures. (1) Survey and locate each peg along the steering bank by selecting from an arc of readings either above or below an existing peg. or (2) Mark out the area with a series of contour lines and align the steering banks to cross each pegged contour line at right angles to the contour. The former method is discussed first.

1. Surveying parallel with the steering banks.

If the selected starting point is on the lower boundary, the procedure, firstly with a Bunyip water level and secondly with an automatic dumpy level is as follows: A peg is to be placed at the selected starting point for the first steering bank, which may divide the area into two nearly equal parts, then one staff of the Bunyip level should be set up against the upper side of this peg. The second operator then places his staff 15 m (fifty feet) away, the distance being governed by the slack of the transparent Bunyip level hose, on what he considers to be the highest point on the arc. The atmosphere buttons should be pressed and readings taken by each man noting the variation in the height of the two staffs. The reading of the forward staff is to be particularly noted. Then with the back man maintaining his staff position, the forward man commences to take more readings as he moves his staff to three or four positions on an arc, with the radius of the circle represented by the 15 m (fifty feet) measure of the Bunyip level. When the point is selected, the lowest of the series of readings, which is then the highest spot 15 m (fifty feet) distant upland from the start, a peg is placed against the staff on its lower side. Then both men should move forward, the back man to the peg just placed by the forward man, and the front man to a new position as before. By taking readings on a new arc, he again finds the highest point and places the third peg.

This method of pegging should continue upwards to the irrigation channel and finish about 20 metres (one chain) beyond the channel on its upper side. A longer peg or a steel post for sighting may be placed at this last point.

If the vertical height from the start to the end of this line is required, then a record of each set of readings of the Bunyip level is kept. The total of the differences in readings then is this vertical height. It is to be noted that three operators are used when levelling and pegging the line of a steering bank with a dumpy or automatic level. They are, an instrument man (surveyor) for the level, a staff man and a chainman.

The dumpy level is located at a suitable distance up the land from the first peg by the surveyor, to take reasonable advantage of the telescopic capacity and thus be able to read a number of sightings from each station (location of the level). The staff man positions his staff at the first peg and the surveyor records the first staff reading. The chainman remains at the first peg holding one end of the measure. The measure may be a surveyor's tape, length of light rope or wire and may be 15 m., 20 m., to 50 metres (50 feet, a chain, or even 165 feet) long, if the land form is large and smooth. The staffman, holding the other end of the measure, walks to, and holds his staff upright, at a spot he considers to be definitely off to one side of the final target area which itself is on the line of maximum rise. The surveyor notes the new reading on the staff then signals the staff-man to try several new positions. The staff-man will now be fairly sure which way to walk so as to arc through the correct location. When the new readings reveal the next high point, the instrument man signals the staff-man to place the second peg. The chainman walks to this newly placed peg as the staff-man, with his end of the measure, walks to a new spot upland as before.

Alternatively the staff man can aim to pick the high point first but then he must test both sides of it to have it confirmed. If he tests two points at an arc span of 15 metres each he will end up doing 20% extra walking. Figure 40, illustrates this point and shows that in one case the total distance walked for each peg is 140 metres whereas with the other it is 170 metres.

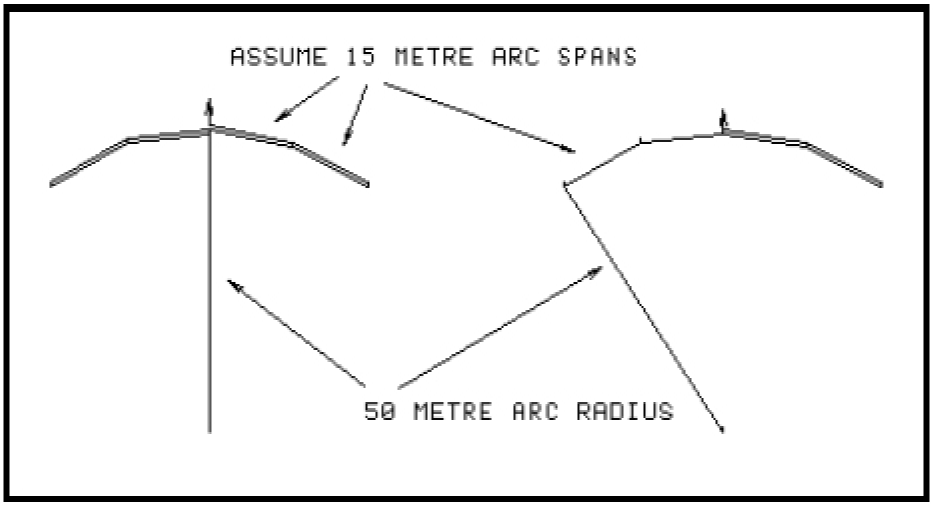


Figure 39 Alternative paths for the staff-man pegging steering bank lines. Tracking out to one side initially reduces the walking.

One end of the measure can be looped around the staff, and each reading of the staff should be taken with the measure fully extended from the chain-man to the staff-man.

On very flat land the pegging of a steering bank line may be done either from the lower side of the irrigation area and working upward, or from the irrigation channel and working downwards. Usually the latter in which case, each sighting locates the lowest point on the arc of measure and thus the greatest reading on the staff.

The line of pegs thus positioned represents, when viewed from the sight peg placed near the irrigation channel, a local line of maximum fall directly down the land. As previously stated, this is an important and distinctive “water-line” of the land.

If a series of these lines were plotted and marked in for various properties a studied way, it would be found that they would have produced various patterns which are as distinctly individual for each area as the contour lines themselves are for different areas. Furthermore, it is possible that the patterns produced could be grouped into definite categories in a similar way that the patterns of land group contours are classified in Keyline. Also it can be realised, that if a very large stream of water was discharged continuously at the top-most peg just below the irrigation channel, then the water would flow down the land on the line of the pegs, albeit spreading. The width of spread being determined by the slope of the land or the presence of steering banks.

The line of pegs may be quite different from expectations, it will, however, disclose the true fall of the land. It can be considered as the general line for a subdivision fence or if it is found to be unsuitable for an initial sub-divisional fence line, it will at least have indicated where another fence could be located.

Further examination of the line of pegs may show that it is in one of four general patterns: (1) It produces two curves in the form of a flat S bend, (2) one large curve or arc to the right, (3) a similar curve but swinging in the opposite direction, or (4) a generally straight line. Also, as with the pegging of the irrigation channel and for similar reason, the line may be irregular and need adjusting.

The closer to the first line that a second line is pegged in this manner, the more closely generally, will the two lines parallel each other down the slope. Once a few lines have been marked in they may disclose the general pattern for the area. It may be unnecessary to locate every steering bank line so precisely with the level. However, whenever there is any doubt as to the course to follow the levelling instrument should guide the issue.

Under the conditions previously mentioned, 45 metres (150 feet) is a suitable distance from one steering bank to the next. Thus, if the first line does not appear to divide the area satisfactorily, a second line is levelled-in forty-five metres (one hundred and fifty feet) from the first, on the side most suitable for the fence line. Once these two lines are pegged in, the rectitude about these proceedings is dispelled. Even to a totally inexperienced person it is immediately obvious, that he has, with this levelling and pegging, achieved a perfect and scientific “down-hill” line.

When a steering bank line is to be also a subdivision fence line, it is of considerable advantage that the line be “formalised” into straights more suitable for fencing. As this “formalising” to straights of the curves of the various water lines, including the present maximum slope lines, contour lines and the lines of falling channels is somewhat of an art as well as a science, it will be dealt with more fully in the next chapter.

The line for the steering bank under discussion is in the middle of an area which may represent the first stage of a particular Flood-flow irrigation project which is itself only a part of the Keyline plan for a farm or a station. The steering bank lines should therefore be located from this middle section back to the start of the area where the irrigation water flow commences. This section could be quickly completed, and thoroughly tested with a full flow of water.

If the first two steering bank lines indicate a definite uniformity of land slope, the third line to be levelled-in can start at a point twice the distance away as the width of the irrigation bays; in this case 90 metres (300 feet). With this third line levelled-in, a fourth line can be located by a measurement half way between the second and third line pegged about 90 metres (300 feet) apart. As soon as this is done, it will again be apparent whether this method of locating alternate steering bank lines with the level is suitable for given area.

The second method of locating the steering banks in the field is to begin by pegging series of contour lines across the area. This method may require more initial surveying, but it may still be quicker in the long run. As a technique, it is especially appropriate if the land surface is somewhat uneven as a result of any number of reasons; such as recent deep cultivation, tree clearing or numerous shallow melon holes (natural depressions). Minor movements of the staff through the arc in the former method, can produce greater height variations than the general fall of the land. Surveying an arc of say 20 metres (one chain) radius from the last peg, may produce multiple high and low points and because the staff is working on a fixed radius from the last peg, the options for the staff-man to select "natural" surface is significantly restricted.

2. Locating steering banks from a contour survey.

A series of contour lines with the pegs located on points representative of the natural surface height and normalised into smooth curves, will provide the best guide. The starting point for each steering bank is selected as before, however the direction to align the steering bank is done by referring to the pegged contour lines. Steering banks follow the maximum slope and so must cross each contour line at right angles to the contour.

If the "surveyor" can obtain both a compass bearing and distance[17], to each peg during the survey of the contour lines and also maintain an accurate record of the relative positions of the various stations where the automatic level is positioned, it will be possible to produce a scaled contour map of the area. Using this map, the optimum layout of the steering banks can be planned. The actual pegging of the steering banks can be related to the existing pegs. Figure 41, below shows an example of this sort of layout.

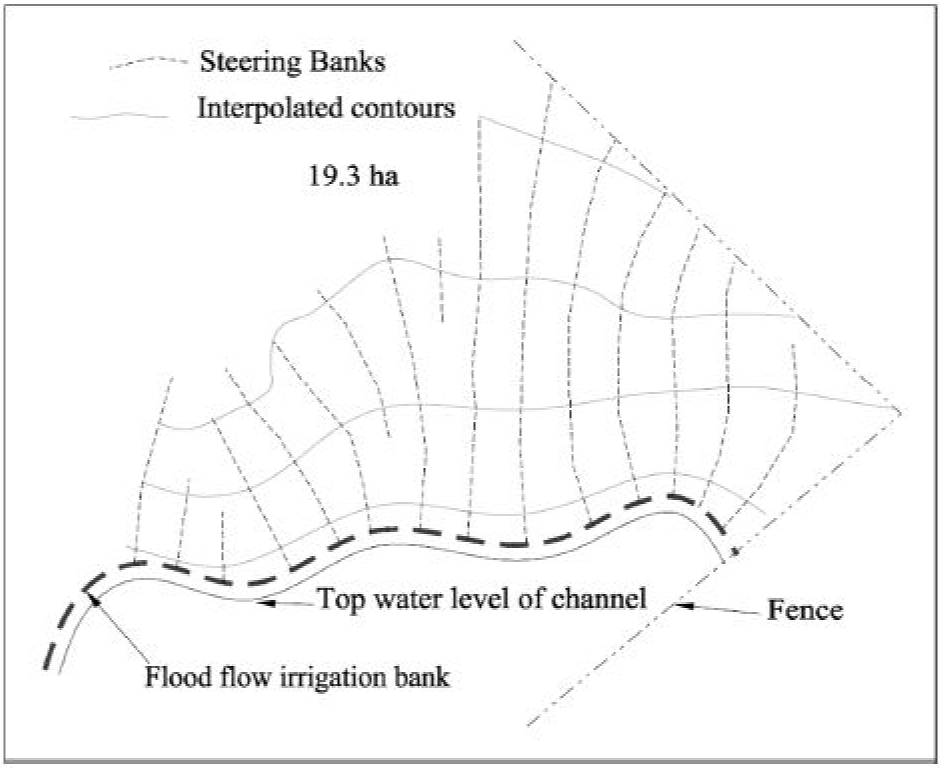


Figure 40 A steering bank layout designed from several contours surveyed through the area. Steering banks cross contours at right angles, which is the maximum slope. Consequently there is very little "cross fall" (sideways slope) in the bays. Land planning, such as laser levelling, is not normally required.

On ridge shapes the steering banks naturally tend to fan out as they descend away from the channel. In the bays toward the side of the ridge the water may tend to drift to the steeper side of the bay. Several land owners have found it quite satisfactory to split bays in half, but well down from the channel, perhaps 200 metres or more. The starting point of the intermediate steering bank is always selected during irrigation, with a view to splitting the observed flow evenly for the two lower bays. If the choice doesn't prove to be quite correct, then the steering bank may be extended a little further up the slope and angled accordingly, to split the flow more evenly.

B. Constructing steering banks.

The most suitable and economic implements for constructing steering banks include a 2 metre (seven-foot) or wider chisel plough, Yeomans Plow or other narrow tyne ripper and a small to medium sized bulldozer with an angle-and-tilt blade. The ordinary farm tractor fitted with rear grader blade (ditcher) is usually quite suitable in place of the small angle bulldozer. The smaller equipment requires more cultivation beforehand and a greater number of sidecasting runs. It should be understood that a farm tractor and ditcher is a very unsatisfactory combination for digging undisturbed earth, but very satisfactory for moving earth which has been well loosened by cultivation.

The construction procedure follows that employed on the irrigation channel bank, except that the steering banks are only half the height and contain less than one-quarter of the amount of earth. Again, unless the grass is short, it should be closely mowed and the grass moved off the line.

The path of the first chisel run is made with the centre of the plough over the top of the pegs. The pegs are then recovered for later use. The second and third runs with the chisel plough are made in the exact furrows of the first run so that the strip, when finally cultivated, is still only about 2 metres (seven or eight feet) wide.

Plate 51 The first of two passes with a grader in the construction of a steering bank.

The small angle bulldozer makes only one run from each side, with the digging point of the blade in the second chisel furrow from the outside of the cultivated strip. It side-casts the earth towards the centre of the strip. After the first side-casting run, the newly placed earth is consolidated and bonded-in by travelling the full length of the new bank with one track of the tractor on the top of the loose, sidecast earth. The second run is then made from the same position, but on the opposite side of the cultivated strip and again the new earth may be consolidated with one track of the tractor. However, if this work has to be done when the earth is extremely dry it, may be better not to try to roll-in the earth with the tractor.

Plate 52 Finished steering banks. These two banks are close together as they channel water down the centre of a long ridge.

In conditions where a grassed area is sod-bound, the above procedure, while producing a bank which works satisfactorily by steering the irrigation water and not leaking, may form a bank which is very lumpy and somewhat unsightly. In these circumstances, the number of chisel cultivations can be increased with the first two or three runs being made with the chisels spaced closer together and with short weed knives attached, but finishing the final run with the standard 30 cm (twelve-inch) chisel spacing.

Under these same conditions, a first shallow cultivation run with a rotary hoe to chop-up the sod, when followed by the two or three chisel cultivations, may assist in producing steering banks of smooth finish.

A first shallow cultivation with a disc or mouldboard plough, if available, may be of assistance in a similar manner, but these implements are generally unsuitable for any other purpose on irrigation land. Their inevitable and continuous side-casting of soil at every operation, tends to change the natural “water shapes” of land, thus interfering with the uniform spreading of the irrigation water.

The lower ends of the irrigation bays, of which the steering banks form the sides, are left open so that run-off from heavy rainfall and drainage water can get away. This run-off water from the irrigation bays may flow directly to a stream below the area, or continue on to lower land which itself eventually drains to a stream somewhere below.

The upper ends of the steering banks, as formed by the equipment, do not join in properly to the bank of the irrigation channel and some work is necessary to complete and tidy up the steering banks at these junctions.

Furthermore, the construction of the steering bank in the above manner leaves a small drain on each side of each bank throughout its length. Therefore, earth stops are placed in these drains 9 - 15 metres (30 - 50 feet) apart, along their full length. The earth for these stops is taken from high spots on the steering banks and high places within the irrigation bays. These earth stops continuously turn the main flow of the irrigation water back towards the centre of the bays. They should be higher than the level of the land and they will need checking and attention for the first few irrigations to see that they perform their function properly. These stops are of great importance to fast economical irrigation. They also cause small ponds of water to lie against the steering banks after each of the first few irrigations. The ponds could greatly assist the grassing of raw earth on the new steering banks. As with the banks of the irrigation channel, time and good management effect the virtual disappearance of the small excavated drains which are associated with the construction of the steering banks.

A problem can arise if water washes out the small earth stops along the side of the steering banks. If this is allowed to continue, the possibility of significant soil wash beside the bank is real. This then can only be remedied by carting in material from outside the site and rebuilding the steering bank so that there is no depression along the side of it. In these circumstances one as yet untried option, would be to construct a double banked steering bank obtaining the earth for the two banks from between them. The section between the twin banks could range in cross section from a narrow “V” to a wider flat bed, which can provide a dry access path to the bottom of the bays.

XIX. FENCING IN KEYLINE

The three main categories of fences are (1) boundary, (2) subdivision, and (3) stock handling. While the difference between these three categories are fairly wide, there are further wide variations within the categories themselves.

The boundary fence is the only type of fence which is precisely located and its straights and corners permanently fixed, without the necessity for any decisions on the part of the owner. The construction means and materials used invariably follow local, district and sometimes national usages. In general, the boundary fence fashions of the district can indicate that they are likely to be the most suitable and economic under the local circumstances.

The introduction of fence wire and wire netting to counter the multiplication of the rabbit population completely changed the fashion of boundary fences. The rabbit may again be considered a menace though it is becoming usual to encounter boundary fences built without regard to this former rural pest. The new fashion in boundary fences appears to be based on the assumption that the rabbit can be kept permanently under control. The dingo or wild dog is still troublesome in some areas so these pests have some influence on the design of boundary fences.

Subdivision fencing is, however, the principal type which now needs a greatly improved technique of planning and location, as well as improved methods and material in the building of the fences themselves.

Adequate subdivision fencing is a major capital cost on any rural land holding and on numerous occasions its final cost will be much higher than the purchase price of the farm or the station. Fencing which subdivides land to the best advantage, also permits effective stock control, which is itself a major factor in soil improvement and production. Adequate fencing enables management to give the grass of each paddock its time to re-grow.

Holding stock on the pasture of one paddock for too long a period, is somewhat like trying to produce sugar but cutting the top off the cane each time it appears above the ground. Good grass, like all other crops, needs its time to grow. All it needs is to be left alone. Then a good crop can be harvested by the stock later on.

If this occurs at the right time, good pasture grown on fertile soil is still by far the cheapest and best stock food of all.

When pasture grows upward its roots will grow downwards, if soil conditions permit. The plant’s shoots and roots increase in size till the plants approaches maturity and the flowering stage. If the leaf area is then removed by mowing or a quick grazing the energy reserves of the large root system will be used to initiate a quick regrowth. The plant can not maintain the large root system and much of it dies and is sloughed off. The recently dead roots of a good mixed pasture are the basic food of soil life and help produce climaxes in the soil biological development. Mixed pasture roots can be the best and most economical organic material. The deeper the roots and the greater the quantity of high protein root material produced, the better for the whole dynamics of soil life.

Set stocking is the common method of grazing pasture but set stocking amounts to a constant nibble. Perhaps once a year the plants do “get way from the stock”, but even then the plants usually set seed and the protein in the roots is lost to the soil organisms. However with the aid of good fencing and subdivision paddocks, pastures can be controlled and managed to produce more and deeper roots. A cycle of improvement for soil, grass and stock could be the result. Abandon the constant nibble of set stocking and three to six times the quantity of roots can be produced by pasture in several good eat down and re-grow cycles each year. The benefit of this system of management for cattle, will rival the benefit for the soil itself.

Furthermore, it seems certain that the greatly increased grass production which results will also be of better nutritive quality as well as being more suitable for stock to eat. We believe cattle will graze for a certain fixed number of hours each day and no longer, even when inadequately fed. If the grass is too short the cattle are unable to collect enough to eat. When grass is at the correct stage of growth, cattle in particular can curl their tongue around a large sward and gather more of it into each bite.

Good subdivision of farm and grazing properties is one of the principal factors in the improvement of soil fertility and a major factor in increased production.

It is claimed first of all that no bases of planning, other than those belonging to the Keyline approach, can possibly satisfy all the basic requirements of rural land development, which must include that of making the best possible use of every natural and renewable resource belonging to a particular property. If this is so, then it is true to state that it is a rarity to find any farm or grazing enterprise which has been correctly subdivided;

this is without any criticism of the actual fences and their more often inadequate gateways.

Therefore, the first improvements to be made to the present unplanned or wrongly planned subdivision of land, is the general acceptance of the relative position of fencing in the priorities of planning as disclosed in the Keyline Scale of Permanence.

On any property where its own water resources can be developed economically and used to produce irrigated land, the fence which divides the irrigated land from rain-pasture or rain-crop land, is of the first order in subdivision fences. The position of the fence above the irrigation channel should be such that any servicing of the channel is not impeded by the fence being too close. The gateways should be placed with proper regard to the water conditions of valley and ridge, as well as providing adequate and workable access.

It needs to be a good fence, since the condition of the irrigated land is a strong incentive for stock in a rain-pasture paddock above it, to test its strength.

Gates need to be more adequately stock-proof than the fence itself since stock, expecting to be moved, tend to concentrate at the gate and as always, those behind push the ones in front.

In the matter of gates, the opinion has been formed after much experience, that by far the dearest gate is the cheaply made farm gate. It goes under various names, such as Cocky’s gate, bush gate, Taranaki gate, Wagga gate, California gate, etc. Because of its continuous tendency to fail under stock stress, being awkward to close and therefore being sometimes left open and by being difficult at most times to open, it causes such a continuous loss of time and effort that, by comparison, the most expensively made steel gate would finish up by being far less costly.

The fence above the irrigation channel will join a fence running down the land to form a side boundary of the irrigated land away from the water supply side. This fence may be part of the boundary of the property.

If the irrigation water is supplied from an earth wall dam built across a stream, then this stream below the dam wall will be either fenced in with the irrigation land or fenced out of it. In either case, the fence should be located from the water line of the stream in the same manner as the fence located by the irrigation channel. Its position is plotted and pegged in a similar manner to a fence beside an irrigation channel and this procedure is detailed later in this chapter.

A fence along a stream needs a minimum and a maximum clear distance from the banks of the stream. It may be the place for a tree belt which, if the creek is fenced in with the irrigation land, locates the permanent fence further from the stream.

Another fence must close the lower limits of the irrigation area. This fence could also be associated with a stream course. The stream may carry water suitable for stock and therefore be fenced in with the irrigation area. The fence then on this lower boundary, would be located in the same respect to this water course as the other two fences were to theirs.

One or both side fences now needs to cross over the stream, over a natural water line, and these fence crossings, like gateways, need to be even more stock-proof than the rest of the fence, and at the same time, be constructed with regard to the high flows of the stream. Flood-gates may be needed and local design may be the style to follow.

The lower border of the irrigation area may have no natural feature to position the fence line, and the land below the irrigation area may simply continue its gentle downward fall. The fence would then be located by the measurement of an appropriate distance downward from the irrigation channel. This should be done in accord with such factors as the volume of the flow of the irrigation stream, the relationship between the amount of available water and the area of land below it which lies in the best position for irrigation.

When there is a choice from the available land, it could be decided that the general shape of the irrigation area should be long and narrow, in preference to a squared shape so that the subdivision within the irrigated land itself could be more simply done on the formalised lines of selected steering banks. Whichever way the selection is made, the local circumstances and the foregoing principles will make the most suitable position more or less obvious. The fence line itself should be located contour-wise and its final lines be those selected to produce a formalised contour. Then the fence itself, as well as filling in with and assisting the overall water use scheme, will serve as a guide for that part of then cultivation of the irrigation area which parallels upward from a lower contour line.

In practice no disadvantages have been associated with the up and down fences which produce the subdivision within the irrigated land, being constructed on the steering banks themselves. However, in this case the original lines produced by instrument levelling, are formalised for the bank construction and so the fence is again a series of straights.

The smaller the paddocks, the higher the cost per area of fencing. Paddocks of square shape and with areas of 256, 64 and 16 hectares (640, 160 and 40 acres) will, with fencing costs at $625 per Km ($1000 per mile), cost respectively $15, $30 and $62 per ha ($6, $12 and $25 per acre) to fence. The differential is actually greater as the paddock becomes smaller, since the higher cost of gateways is again greater in price per acre.

Again, as irrigation flows become greater and the irrigation bays between the steering banks are longer, the subdivision layout of the irrigated land may require that every steering bank be a paddock boundary and have its own fence. There is nothing against this degree of subdivision if it pays, indeed there is a lot to be said in its favour since it simply involves the use of formalised lines for every steering bank.

Furthermore some of these one-bay paddocks could contain stock yards and special buildings such as shearing sheds. And what would be wrong with having a selected irrigation bay as the site for the gardens and orchard of the homestead? Indeed why not place a new house, or even a homestead and all its subsidiary buildings and yards, in such an irrigation bay?

There are vast areas of flat land where a hill or a higher site for a homestead does not exist and where a site adjacent to a river, creek or billabong is often the only choice present. In such cases, a site inside the top end of a specially selected irrigation bay could be ideal.

Most owners would want the greatly improved living conditions which irrigation can bring to the hot areas of generally low rainfall. And many sheep and cattle stations in such areas have major unused and often unsuspected, water resources. Of course, when it rains these special irrigation bays would get wet, but now they could be also irrigated at will.

Likewise, any such area which may be required to be kept dry, could be by-passed in the irrigation cycle, simply by not opening the water-gates which lead into it. Again, in conditions of heavy rainfall run-off, the water-gates to all the other paddocks remain open. Thus, run-off from above the irrigation area could be prevented from entering where it may not be wanted, simply by closing two watergates.

Such matters and their management can be easily planned and economically executed, provided these factors of water lines and water flows, and the general associations of water and the land, are understood. The advantages can be outstanding.

While any main subdivision fence which divides irrigated from rain-land should be considered in regard to its suitability as a site for a permanent tree belt, there will still be a need for tree belts within the larger irrigation areas which will be developed on many flatter land properties.

Young trees, planted following proper soil preparation, grow into effective wind breaks much more rapidly than is generally realised. When it is stated that in five years the belt of trees will be an effective sound barrier, wind brake, shelter belt or what ever, the impression is often given that from planting time until five years hence, a tree is nothing. But a belt of trees at six months and following only its first growth, is something of beauty and satisfaction, particularly so to the planter and owner. At twelve months the belt of trees already takes on a planned, orderly and well-cared-for look which it liberally bestows on all its surroundings. In a very short time the belt of trees can stand alone and no longer need its protective fence.

But in how much shorter time are these stages of growth reached when, as is now suggested, a belt of specially selected types of trees is planted down the centre of an irrigated area and in its own bay, with its own steering banks and fence boundaries and where the belt of trees can be watered at will for practically no cost?

Furthermore, there is always a forestry officer in the vicinity with his sure knowledge to discuss the type of trees, their habits, their advantages and disadvantages aiding the landowner with his decisions. As well as this, behind the officer there is his department which will even grow and supply the young trees to the landowner.

The increasing need for a great deal more subdivision fencing and the rising cost of posts for this fencing, can be offset to a considerable extent by the landsman growing his own fence posts. He can very simply create his own perpetual forest (tree belts) for this purpose.

With the success of the preservation treatment of fence posts by both the pressure and the sap-replacement methods, posts of small diameter cut from young trees, are made to last as long as split posts from selected old trees.

These smaller, treated, round, posts are usually pointed and driven into the ground.

Seedling trees, planted for the purpose of supplying fence posts on “Nevallan” provided some useable posts in only three years.

The idea is to plant four or five rows of trees, located as discussed for permanent tree belts. The distance the trees are apart in the rows can be as close as 1.5 metres (five feet), with a spacing between the rows adequate for cultivating with a tractor and chisel plough say 3 -3.6 m (10–12 feet). Trees can then be cut for posts after three years, when each second or third tree is taken as required. The trees are cut off with a slanting cut about five inches above the ground. The remaining stump will soon “sucker” and when this new growth is sufficiently advanced, one selected stem is left to grow again into a fence post size, and all other stems are cut off. This new tree, with the full root system of the cut tree remaining, will grow very rapidly. By judicious selection of trees for removal and thoughtful management, a valuable shelter belt and a perpetual supply of fence posts can both be attained.

From the national viewpoint, Keyline water control systems on both hill land and flat land could make reforestation on a grand scale be both practicable and profitable. It is suggested that some aspects of the Keyline plan offer a most satisfying solution to the ever growing and serious problem of Australia’s inadequate and dwindling forestry resources.

As is abundantly evident crop land, pasture land and forestation can be in competition with one another, to each other’s detriment. Keyline planning relegates each to its proper locality and function and thereby assists in maintaining high quality production in each case.

A. Normalising and Formalising

Formalising is a procedure used to locate fence straights along curving surveyed lines, and normalising usually proceeds formalising.

1. Normalising

Normalising, in the sense used previously, is the art and science of adjusting the location of surveyed pegs on deteriorated land with slightly altered surface. The aim is to produce practical and workable lines for contour and graded channels, drains and guide-lines for patterns cultivation. The object of normalising then is to produce curving lines the same as would have been surveyed if some of the surface had not been slightly altered by erosion, cultivation equipment, old roads and such like. For example, even recent wind erosion on some lands of little slope will cause disparities in the surface of land and produce variations in levelling instrument readings which may be as great as the general difference in levels found in a distance of a couple of kilometres (over a mile). Thus a local variation, at only 15 metres (fifty feet) distance, may be equivalent to that of the general fall at a distance of 300 metres (1,000 feet) or more away.

2. Formalising

Formalising is the art of producing straight lines from the smooth shaped curves of normal land forms, to replace the curved lines and, at the same time, maintain the principal values and virtues of the normalised lines.

The art of normalising and formalising are also applied to those other water lines referred to in the discussion on the planning and levelling-in, of the steering banks.

The function of formalising, as it applies to the fencing of irrigation land, has two forms. One may on occasions, apply to the fence along the irrigation channel or similar contour divisions, the other, to those interior subdivision fences of irrigated land which go along the fall of the land. Both forms also have an important application in the subdivision of non-irrigated land.

Dealing firstly with the type of fence which is to be placed on a steering bank we refer to figure 42. The series of crosses represents the true line as pegged with the aid of the levelling instrument; the wavy line, whilst being off true, represents the best curved form of the line, which is practical for the construction of the steering bank; and the line formed by the series of straights is the formalised line and represents the nearest to the true line that is practical for a steering bank which may have a fence on it.

In some circumstances the pegs, as represented by the crosses in Figure 42 may not favour normalising because of wide variations from any form of line. They will, however clearly indicate the true general downhill direction and so one or more straights may be more suitable when selected directly, than by first normalising the line.

The formalising of the irrigation channel line for a fence position aims to produce the “straights”, either above or below the appropriate bank of the channel and parallel to it in a general way and at a specified minimum and maximum distance from the channel bank. For beef and other types of general production it has been found, from experience in the management of irrigation land including the various systems of flood and flow, that where water is distributed from channels, 6 and 9 metres (20 and 30 feet) are suitable minimum and maximum distances for the fence position from the nearest channel bank.

Referring to figure 42 on the following page, the curving parallel line across the top of the page represents the bank of an irrigation channel, in which the water flows from left to right. The irrigation land lies below the channel and the fence is planned for above the top bank.

The purpose of the fence, is to divide the irrigated pasture from the rain-pasture land above it.

This work, as all other planned land development, may be first plotted on paper if the area has been suitably mapped. The result can thus be “seen” in a general but practical way. The work will also be measured and “sighted-in” on the land itself. The procedure for this is as follows: One man can do the pegging of the fence line, but is a big advantage to have a helper.

Ten pegs 1.2 m to 1.5 m (four or five feet) long and white-topped for easy sighting, will be needed. A 50 metre tape may be carried or the surveyor may rely on “pacing”. The term “surveyor” here is used in the wide sense of the word, for the man who makes the decisions, as well as in the accepted sense. He may be the owner of the property, the manager, a supervisor, a foreman or the temporary boss.

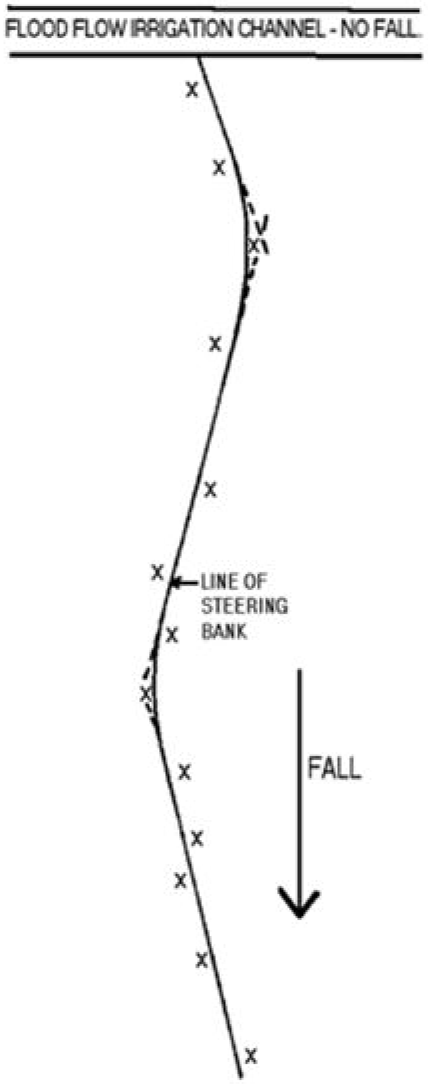


Figure 41 Pegging the line for a steering bank. The crosses are the points of maximum fall located by the level. The curved line represents the steering bank. The three straights show the formalised line of the steering bank if a fence is to be located along it.

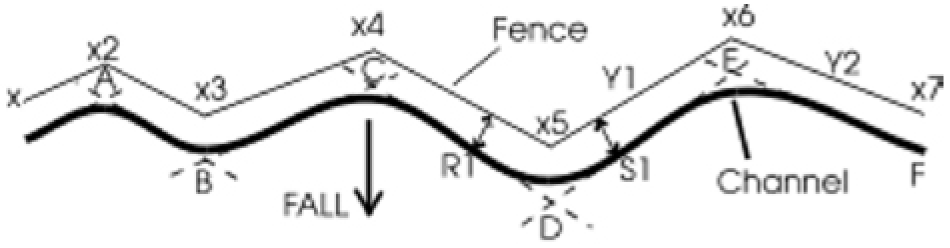


Figure 42 Locating a fence along an irrigation channel to divide rain land from irrigation land.

Referring now to figure 43 in which the dark wavy line represents an existing channel, the first peg is located at “x” (left side of the figure), by measuring 6 m (20 feet) up the slope from the bank, at a right angle. The left side of the figure is the west end of the bank. The surveyor then proceeds to point “A” which he locates by sighting to right and left along the two curves, then choosing the point “A” as the junction of these two lines if they were extended until they crossed. He places a temporary peg at “A” and then measures 6 m (20 feet) up from “A” and directly away from both straights. This spot is pegged as the second fence point, x2. Sighting back from the fence point x2 to fence point x, he will see that this straight of the fence will be the required 6 m (20 feet) minimum distance everywhere from the bank and that the maximum distance from bank to fence is at x2.

He now proceeds to point “B” which he locates precisely as with point “A”, only this time the point is below the upper bank and in the channel itself. He now walks north on a line that divides in half the angle A-B-C and measures the 6 m (20 feet) minimum distance but this time the starting point for the measured distance is from the bank itself as at x. The third peg of the fence line is placed at x3.

In review, he has now placed x the starting peg; x2, a peg in correct location in respect to the flat valley shape which the curve upland represents; and x3, a peg in correct location in respect to the flat ridge shape which the curve down-land has denoted.

He proceeds in like manner to “C” valley shape and places x4; on to “D”, ridge shape, and places x5; now to “E” a larger and flatter valley shape and places x6; and so finally to “F” where x7 is placed in the same manner as the first peg x.

This should be the completion of the final line of the fence, unless it needs to be altered after checking.

The surveyor now proceeds to examine the fence line by checking the places where the line reaches the maximum distances from the channel bank. The obvious points to examine are R1, S1 and at peg x7.

The only ways to retain the minimum distance while reducing the maximum distance are: (1) by making an extra straight in the fence line, and (2) by the inclusion of a gateway at one of the pegs, which could represent a corner of the fence line.

Referring to R and S on the diagram where the fence is furthermost from the channel bank, new fence points may be located at each, in the same manner that fence point x3 was located from “B”. An extra straight, R1-S1, would result in the fence to bank distance being equal to the minimum at points R1 and S1.

In this operation, care is taken to see that some other points on the lines x4 to R1 and S1 to x6, do not now fall within the minimum distance of 6 m (20 feet) thus requiring some little adjustment upland of points x4 and x6. It thus becomes apparent that the addition of a new straight, to what can now be regarded as the first trial line, may make it necessary to check the fence points again from start to finish.

3. Gate locations

Gates, located at fence points, by being in effect short straights, act in a similar though lesser manner to the extra straight R1-S1. Before the final fence line is decided upon, gateways need to be located. Two general errors are to be avoided with gates on irrigated land. Firstly, too few gateways are usually provided and secondly, the gates themselves can be inferior for the job.

Referring to the case illustrated in figure 43, there are at first sight four obvious gateway positions, namely at x, at x3, at x5 and x7 which should all be used. Even so, the distance apart of gateways at x5 and x7 is too great and at least one other is required. The selection of a site for this gateway can be at one or the other of points Y1 and Y2.

Now the reasons for these selected gateway sites are, respectively: x is closest to the delivery point of the water and a gateway for service and management is required. Here it may also serve for stock movements. x3 is on the centre line of a ridge and also lies at a suitable distance from gateway x. Points x2 and x4 are not as suitable since they lie in the centres of flat valleys which do not usually withstand traffic and tramping as well as ridge shapes do. x5 again is on the centre line of a flat ridge and its position is suitable in relation to the gateways at x and x3. x7 at the limit of the channel is another “must”. Now only a gate between it and x5 needs to be located.

Point x6 is not desirable since, like points x2 and x4, it lies in the centre of a valley form.

The decision between points Y1 and Y2 as the one most suitable for a gateway, can be decided by reference to the general direction of the steering banks in this part of the irrigation area. For instance, if the steering banks swing to the west in relation to the eastern boundary fence which may run north and south, then a gate at Y2 would be the one to select since the fence line down-land that would be associated with this gateway, will then divide the area more equally. If, on the other hand, the steering banks tend to the west, for similar reasons, Y1 would be the one to chose.

4. Final considerations before construction.

Now with the line of the fence clearly marked with corner pegs and the position and exact width of gateways pegged, the surveyor should walk the line for the final adjustment of the fence position.

The fence line is now comprised of a series of longer straights which represent the fence itself and a series of short straights which indicate the gateways. These final adjustments of the fence line aim to maintain the fence between the minimum and maximum distances from the bank.

The first time a fence of this type is located by a surveyor, he would do well to follow this procedure in detail. However, once he is experienced by having completed his first such fence, he will be able to shorten the work by making decisions on pegging the gateways and completing fence line all at the one time.

The procedures for positioning a fence above a single bank irrigation channel are exactly the same as those previously described except in one respect only. The minimum distance has to take into account, that for this type of channel, the water flows on the land above the channel. Either the average width or maximum width of the water flow is added to the 6 m (20 feet), which was used as the minimum width for working and management. So, if the stream flows 11 m (36 feet) wide above the channel bank, then the calculation for the minimum distance above the bank to the fence line, is 6 m plus 11 m which is 17 metres (20 plus 36, or 56 feet).

An irrigation area needs its fair quota of trees, firstly for stock shelter and secondly for wind-breaks. The belt or line of trees, can be very suitably associated with this subdivision fence which divides the irrigation land from the rain pasture land above it.

In the case of two rows of trees of medium spread, 14 metres (46 feet) will need to be added to the minimum distance of 6 m (20 feet), so that the minimum distance would be 20 metres (66 feet) above the bank, or the water line as the case may be, for this permanent fence line. A second fence below the permanent fence, is then needed for the protection of the trees from stock during the first three to five years of growth. This second fence can be classed as a temporary fence but it must still be fully stock-proof to serve its purpose.

Farm and grazing boundary and subdivision fencing needs will never be served by only one general type of fence. Only by classifying fences into types or categories will logical decisions on the selection of the right fences for various purposes, be possible.

XX. CULTIVATION OF IRRIGATED LAND

A. Purpose of cultivating irrigation land

There are three main purposes of cultivation on irrigated land for grass production. The type, form and timing of cultivation should be so planned that these three purposes can be accomplished at once, and preferably each time cultivation is required.

The three purposes of cultivation on any Keyline project are (1) as an aid to the development and continuous improvement of the soil's biological fertility, (2) for the soil to be uniformly spread with water both from rainfall run-off and from irrigation, and (3) for the preparation of the land for sowing or the actual cultivation when the seed is being planted.

In (1) the mechanics of this cultivation should be such that the soil's aeration is greatly improved and the living soil is not inverted, chopped up or mixed with large amounts of subsoil. Most soils lack humus and have very limited capacity to quickly adsorb water. Also they have become compacted and what soil life exists can only occupy a very shallow surface layer.

In (2) the uniform spreading of the water, reference is made to Keyline cultivation and the geometry of Keyline already discussed elsewhere.

The main purpose of (3) is often a purely mechanical solution to the problem of controlling the present growth by killing it in order to successfully plant, and at the same time promote the growth of, new plants. But a cultivation which is successful from this last point of view can, as a continued process, progressively deteriorate the soil.

Occasionally the first consideration in a newly developed farm irrigation project is the quick wetting of as large an area of land as possible. This may be when there isn't time or equipment available to prepare the soil for planting better species of grasses and legumes. It can be more important to produce a quick growth of even relatively poor pasture from the existing vegetation rather than do that which is the best for the land and for the soil itself. But it would be better to loosen the soil and to cultivate to a pattern that will ensure a uniform spread of water.

Diverted water may fill a new dam before rain falls making irrigation water available for the new area. On the other hand, a dry landscape may delay any use of the irrigated area until heavy rain falls and run-off fills the supply storage. In this latter case full use may already have been made of any fodder on the area and the cultivation of the land for the improvement of the soil and the uniform spreading of later irrigation waters can proceed immediately without any disadvantages in lost stock feed.

In the case where the planting of new pasture species into a sward which is somewhat less than satisfactory is the appropriate course, the three purposes of cultivation may be fulfilled at one and the same time by planting the new seed with a chisel-seeder, adjusting the depth of the cultivation to suit the present stage of the soil's development and placing the seed at a depth in the chisel furrows which will promote the best germination and growth.

B. Cultivating equipment

Each type of cultivating implement has its particular uses and special advantages and disadvantages.

1. Mouldboard plough

The mouldboard plough was long considered by some to be the best implement to mechanically prepare a "clean" seed-bed when the soil is moist and the prime consideration is the quick, if temporary, control of the grass and weeds of the cultivated land. By precisely turning the soil and growth upside down, it presents a "clean" soil surface into which crop seeds can be sown easily. It would be hard to find other favourable aspects of this piece of equipment for irrigation land.

2. Disc plough

The disc plough in its lighter weight versions, such as those combining seeding equipment, has its main advantages under somewhat drier conditions than those mentioned for the mouldboard plough. It is used to produces a very fine seed bed for the precise planting of grain on the "firm" ground below or at the "bottom" of the shallow cultivation. The seed is covered with a fine to a dusted soil mulch which forms an effective barrier against evaporation. Available moisture is retained at the "firm" seed-bed and so germination and first growth is promoted. However the finely cultivated soil may quickly seal in any shower and the critical air movements within the soil are immediately and seriously affected. Then the "dust-mulch" which retarded evaporation can become an equally effective a barrier against the favourable entrance of rain when it falls later. Increased run off results and can produce erosion of the de-structured topsoil. Under these conditions the disc plough can be a fertility destroyer.

The heavier and bigger forms of the disc plough are mechanically very effective for their ability to “chop up and turn under” various types of light scrub growth with speed and reasonable economy. The decomposition of the buried plant material generally takes a long time and there is usually little benefit to the soil.

Continuous use on the same soil of either the mouldboard or the disc plough, will in general eventually reduce the fertility of the soil. Their use in areas of good soil and adequate rainfall in climates much cooler than tropical, can continue for a long time without any notably bad effect and, some farmers can hold and even improve the fertility of their soil. However, it may take exceptionally good soil management practises and the use of special grass and clover mixtures to prevent rapid soil deterioration when this equipment is used in humid and tropical conditions. Cultivation procedures invariably become more and more critical for soil fertility as rainfall and the temperature rise.

Also, side-casting implements such as the mouldboard and disc ploughs are better excluded from use within the irrigation land because of the compounding effect of moving the soil sideways with each pass. This progressively alters the shape of the paddock and the desired flow path of run off water.

3. Rotary hoes

Rotary hoes also have their good and bad features. In conditions of heavy weed growth on intensively cultivated soils, such as those used to grow garden and truck crops, the rotary hoe will mulch the growth and mechanically incorporate it into the top soil in a very efficient manner. However, if used on land with poor clayey soil and with little growth they produce a fine cultivation which seals immediately when rain falls thus drastically affecting soil aeration and soil fertility.

4. Tyned implements

The tyned type of implements, ranging from light cultivator to the strong and “go-anywhere” chisel ploughs *and subsoil loosening noninversion rippers like the Yeomans Keyline Plow with Shakaerator (originally called the Yeomans Bunyip Slipper Imp with Shakaerator)*[18], are generally much less destructive to soil no matter how inexpertly they are used. When used in a manner that takes proper heed of soil development and fertility, they become an outstanding and economical tool for soil improvement. In the moist conditions mentioned as the outstanding ones for a mouldboard plough, the use of tyned implements for the sowing of wheat may result in a lighter crop, however their continued use would be less damaging to soil fertility. They are more likely to improve the soil and within a short time, produce better food-quality grain more economically and improve the yields.

The outstanding way to convert poor earth into highly fertile soil in a short time, is through the proper development of pasture and the chisel type plough and Keyline plow are the outstanding implements for this. In the development and continuous improvement of the soil of irrigated land, these machines are supreme. Even if another cultivating implement is at times used, the special cultivation should be followed immediately by a cultivation with a subsoil ripper or chisel plough.

The depth of any cultivation, including the use of other implements as well as the chisel plough, must always be determined in relation to the present particular conditions and depth of the soil.

C. Keyline cultivation

Although the cultivation pattern for the uniform distribution of water is dealt with in earlier chapters it is appropriate to review in this chapter some of these techniques of cultivation.

The shape of the irrigation channel gives an immediate clue to the shape of the irrigation area land. If the channel is close in form to a straight line the land shape is extremely large and very uniform. In these conditions, a contour line half-way down between the irrigation channel and the lower end of the bays, one other along the lower boundary of the irrigation area will, in all probability, follow the line form of the channel.

Water will spread in the desired way when chisel cultivation is done either of two ways. (1) Parallel downward from the irrigation channel or other contour line when the curve of the line indicates a valley shape, or

(2) parallel upward toward the irrigation channel from a lower contour line when on a ridge shape.

Both will have the desired water-spreading effect.

When cultivation is done on pasture land immediately after being eaten off, the old pasture is left intact with its soil in the best condition for immediate irrigation.

However, where the irrigation channel form has produced curves which swing both upward towards the rise and downward towards the fall of the land, these curves clearly indicate the presence of both valley and ridge forms respectively, even though these forms can be flat enough to escape the notice of the naked eye. The water flow will be affected by these shapes and if no measures are taken to spread the water, it will follow its natural path drifting sideways from the flat ridge form to the flat valley form, within the limits of the steering bank sides of the irrigation bays. Whilst a good spread of water may still result without Keyline cultivation on land of little fall which is also uniform, cultivation will nevertheless improve this factor. But it is still necessary for rapid soil and pasture development. Then, the pattern ploughing of Keyline cultivation will simultaneously consolidate the continued even spreading of the irrigation water, improve both soil and pasture and, if desired, new seed may be sown into the present irrigated sward with the cultivation.

In the circumstances which are clearly shown by the above cited curving shapes in the length of the irrigation channel, there are only two patterns of cultivation to employ: (l) The valley shaped areas which lie within and below the upland swinging curves of the contours are cultivated parallel downward, and (2) the ridge shaped areas, which lie between the downward swinging loops of the channel and the lower marked-in contour lines, are cultivated parallel upward from a specially marked contour line or lines below. The effect of these cultivation lines and furrows is to moderately oppose the natural flow path of the water and cause the flowing water to spread uniformly.

For these cultivation purposes, a contour line is pegged in and marked with a suitable furrow across the area in the position stated. A similar line is placed near the lower boundary of the irrigation land or a contour fence line can serve the same purpose. These guide-line furrows should be prominently made perhaps with a channel-maker, a delver, a ditcher or a large single-furrow plough, whichever is available. It is desirable that they should be easy to follow for several years, they should not however be an obstruction to station implements and vehicles.

The preservation and usefulness of these lines can be enhanced by sowing a special grass into the newly made furrows. Another simple means of preserving the marked contour lines, is that of leaving a four to six-foot wide strip of land in a permanently uncultivated condition on one or both sides of the furrow, or where a large area is being dealt with, to leave a strip of land out of cultivation but wide enough for a farm road.

lf it suits the stock position at the time water is first available, the whole of the prepared area should be Keyline cultivated to the appropriate depth according to the soil conditions, then immediately irrigated. Preferably the man who does, or is in charge of, the cultivation should be the one who does, or is responsible for, the irrigation. This man should constantly follow the water as each bay is irrigated this first time and note carefully how successfully the water spreads. Preferably he should carry, as well as a shovel, a few pegs, using them to mark areas of less effective spread in case correction is attempted later.

In flat land using Flood-flow irrigation the performance of the steering banks and the effectiveness of the stops in the small excavated drain beside the steering banks are kept under check and adjusted as required.

It is important that all the construction work be fully effective. Water should always be kept under complete control. No leak, even of small proportions, should be permitted from the irrigation channel. Water gates must not only release the irrigation stream effectively into the irrigation bay, they should also adequately shut off of water when they are closed. Any leak at a closed water-gate is undesirable.

The steering banks likewise must do more than just their part in steering the water down an irrigation bay. They must also ensure that no water returns to a bay on which irrigation is just completed and that no water escapes ahead of its time into an adjacent bay on which irrigation has not been started.

For the first few irrigations the operator should also check the time required to cover each bay and record it against the number of the bay. This patrol and reconstruction work is done and the times noted and later irrigations could be completed without the single operator moving from the immediate vicinity of the irrigation channel and its water-gates. Thus, the only work in irrigation is the walking along the irrigation channel and opening and closing water-gates according to the time record.

The amount of irrigation water which one man may effectively control in Flood-flow irrigation is therefore naturally limited only by the number of water-gates that he can open and close in, say, half all hour. If he can open and close ten water-gates in this time over a distance along the irrigation channel of 250 yards, what is there to prevent him irrigating 40 acres each hour, providing that enough water has been collected and that the area of land is large enough for this rate of irrigation?

Obviously there will be limiting factors which will govern the initial irrigation rates, but these limits are much more likely to be imposed by factors of water or land, long before even a single operator’s capacity to control water and irrigate land has been reached.

In the cultivation and enlargement of irrigation land it should be continually kept in mind that there are hazards to be avoided as well as the advantages to be gained, from the irrigation process. The good, complete and fertile soils of nature are not associated with the higher rainfall areas but with those where the rainfall is from 400 -750 mm (16 -30 inches) per annum. This in addition to the equivalent of an extra 450 mm (18 inches) of rainfall as irrigation water, is thus more than sufficient to cause serious soil leaching, particularly where the climate already provides 500 mm (20 inches) or more. The over-leaching of essential minerals from irrigated land can only be avoided by the strict control and limitation of both the amount of water which goes into the soil and the time during which the water is in contact with the soil. It is essential therefore that irrigation procedures should water the land as quickly as possible.

D. Fast irrigation

The speed of water application in both Keyline Pattern hillside irrigation and Flood-flow flat land irrigation is such that both the hazards to both soil fertility and soil improvement are completely offset. Indeed it could appear that the completely opposite effect of too little water entering the soil at each irrigation could be a problem where soils are generally compacted and infertile. However, the first (50 mm) two inches or so of applied water is always very rapidly adsorbed into highly fertile soil, and into compacted

poor soils when they are appropriately cultivated either with a chisel plow or subsoil ripper. The objective and the result of irrigation should always be the improvement of the soil.

XXI. BIOLOGICAL SOIL FERTILITY

Biological soil fertility is a product of management. The purpose of this chapter is to infuse some realistic optimism about soil and at the same time, establish a practical and enlightening understanding to support the various themes of this book.

A. Previous wrong rationale on soil fertility.

One of the great obstacles to the proper development of the farm and grazing landscape is wrong thinking about soil. The development of land depends in the first instance on how the farmer thinks about his soil. If he thinks correctly about his soil, he has a chance of doing the right thing by his land but if he doesn't, he won't have a chance of doing the right thing by his land, even by accident.

The two statements quoted below made over a quarter of a century apart represent only too well the attitude of agriculture's officialdom to soil.

It was over a half a century ago that the father of American soil conservation, the late Dr. H. H. Bennett, wrote in his book "Soil Conservation":

"Lack of foresight and restraint … has created in this country a land problem of tremendous implications. What makes the situation so grave is the irreplaceable nature of soil. Once this valuable asset leaves a field, it is as irretrievably lost as if consumed by fire. Soil is reproduced from its parent material so slowly that we may as well accept as a fact that once the surface layer is washed off, land so affected is, from the practical standpoint, generally in a condition of permanent impoverishment. As nearly as can be ascertained, it takes nature, under the most favourable conditions, including a good cover of trees, grass, or other protective vegetation, anywhere from 300 to 1,000 years or more to build a single inch (2.5 cm) of topsoil! When seven inches of topsoil is allowed to wash away therefore, at least 2,000 to 7,000 years of nature's work; goes to waste."

In April 1965, in the publication, "American Agricultural Trends", which was compiled and issued by the United States Information Service, contained 16 items of agricultural interest. The last, under the heading "Small Sheet of Topsoil Sustains World's Life", reads: "All the world's human life depends on the fertility of a thin sheet of the earth's topsoil, covering one-tenth of the earth's total surface and forming a storehouse of plant nutrients only about seven inches (17.8 centimetres) deep. It takes about 1,000 years to build up one inch (2.5 centimetres) of topsoil. Wind or water can take that much away in a few months unless the surface is protected."

It is no wonder that, when such hopelessness is recorded by supposed expert authors and mistaken conceptions of soil still so widely proclaimed, that farmers and graziers are adversely affected and their land suffers needlessly.

When wrong attitudes are combined with inappropriate cultivation methods the results are disastrous. For instance if top soil 5 cm (two inches) deep is cultivated 10 cm (four inches) deep with a mouldboard plough, the living soil is buried under 5 cm (two inches) of inert sub-soil. The soil species and communities may be cut off from adequate air supply, severed from capillary moisture supplies from below, exposed to abnormally extreme temperatures and have their general development greatly disturbed.

B. Soil Fertility - A realistic attitude

If the process of rock disintegration is the first phase in the natural soil forming process, in human terms, it takes a long time. However the time has already passed. Now subsoil, the layers of soil-material beneath the top soil, exists in relative abundance under most of the world's agricultural lands. This is almost universally the situation whether the topsoil has been lost through man-caused soil erosion or not.

The second part of the soil forming process is a biological one. This biotic or organic phase under any climatic conditions that permit agricultural pursuits is extremely rapid and by comparison, virtually instantaneous. The time requirement in this second phase relates more to the life cycle periods of various soil communities; the bacteria, the fungi, the earth worms, the grasses and plants, plus the animals and birds that invade the soil in search of their food.

Earthworms can breed in two to three months after hatching from egg capsules that may produce 20 live worms. Hereafter this hermaphrodite breeds almost weekly in good soil. A hectare of fertile soil will contain two and a half tonne (one ton to the acre) of earthworms. Each worm can excrete more than its own weight of humus-laden casts daily. The availability of nutrients in worm casts is many times that of the surrounding soil.

All forms of life require two things for optimum development; good living conditions, which embrace air (oxygen), moisture, warmth, space and a plentiful supply of suitable (e.g. high protein) food. When these conditions exist in the soil in the right combination there is a soil climax.

In this second phase, the potentially rapid soil forming process, man can intervene acting as a catalyst to enhance and speed up, the various biotic and soil climatic associations involved. In this way man can help transform the inert soil-materials of the subsoil into living top soil in as little as two or three years. Beyond this period of time, the soil will continue to improve according to the manner of the care given to it as part of the general management of farm or grazing properties.

C. Soil-building processes accelerated.

Any present fertility, be it only a smear, or some centimetres (inches) deep, can be used to great advantage in the planned process of soil improvement, by regulating the depth and the type of the cultivation accordingly.

The intention should be to use the living top soil for a kind of "yeasting" conversion. Burying or mixing the topsoil with too much dead sub-soil may overtax and slow down the soil building process. On the other hand cultivation, with a chisel type tyned equipment, if done to 10 cm (four inches) total depth would leave the top-soil and subsoil where they should be i.e. not inverted. It also promotes aeration where needed, accelerates the vital processes of the soil and leaves the smaller section of disturbed sub-soil in the ideal position and condition for roots to extend into it. Unfortunately deep work with a chisel plow brings some of the subsoil earth to the surface by and so limits the depth of the initial cultivation.

1. Depth of cultivation is often critical.

Considering a chisel plough, as the 50 mm (2 inch) wide points pass through the soil, any subsoil in front of each point peels up toward the surface. Deep cultivation is thus impractical till the life in the soil has grown to deeper layers.

In the granitic condition recently mentioned, it would seem that any depth of cultivating could be too deep. Ideally, to use the little soil present to the best advantage, tyne spacing could be very much closer and penetration depth at the commencement somewhat shallower. In this type of soil and sandy soil generally, there is less need for deeper penetration to provide air. A fine surface seal usually causes any lack of air in these soils. With this broken, the air penetrates readily through the sands found usually just below the surface soil.

The depth of the cultivation in similar conditions to those described previously, is not so critical. If there is no soil to use, too deep a penetration would induce rapid waste of the soluble fertiliser downward, reducing the all important initial growth of the new germination. A cultivation dug deeper than necessary, will increase the cost.

There is no need to be pessimistic about soil when soil making can be rapid and cheap. While it is true that only one-tenth of the earth's surface is covered with soil and not too much of this could be classed as highly fertile, it has to be realised that agriculture itself can be a soil-making process.

It may appear that the farming and grazing of land has resulted thus far in more destruction of soil than its construction. Many books written on the ravages of soil erosion would seem to confirm that this is so. All soil can be improved and the relatively larger areas of poor soil can not only be made fertile, but their biological processes can be greatly deepened bringing into the soils productive cycle more nutrient elements than are presently used.

D. The Development of Narrow Tynes (by A.J. Yeomans)

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 rapid development of soil fertility can occur if sufficient quantities of dead vegetation and animal manures are available for composting and the composted materials are blended into inert subsoil.

For broad acre 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 boat's 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 tynes, 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.

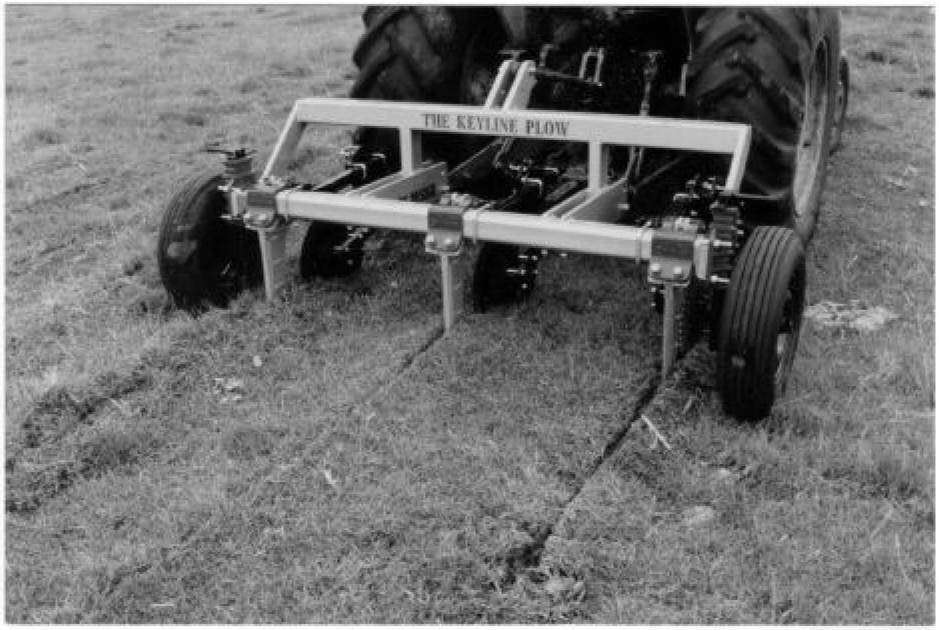


Plate 53 A small three point linkage Yeomans Keyline Plow fitted with coulters and depth control wheels.

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.

Plate 54 Allan Yeomans shows three of his patents. Rigid, simple shear pin system uses inexpensive round steel bar. New "Leap Frog" digging points fit behind used ones, which means no throw away metal. Self locking track down the back of the tyne enables quick tool changes. Photo shows weed knives attached.

In addition, the use of this new plow enables the soil to absorb high quantities of run off from storms, and heavy down pores. This is the run off that normally fills dams, and can often cause erosion. These effects have to be 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 sub-varieties 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 but 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 the combining in the soil of dead plant material, air and water. Activity then starts, bacteria, fungi, actinonycetes 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 broad acre 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. Tine spacing was 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.

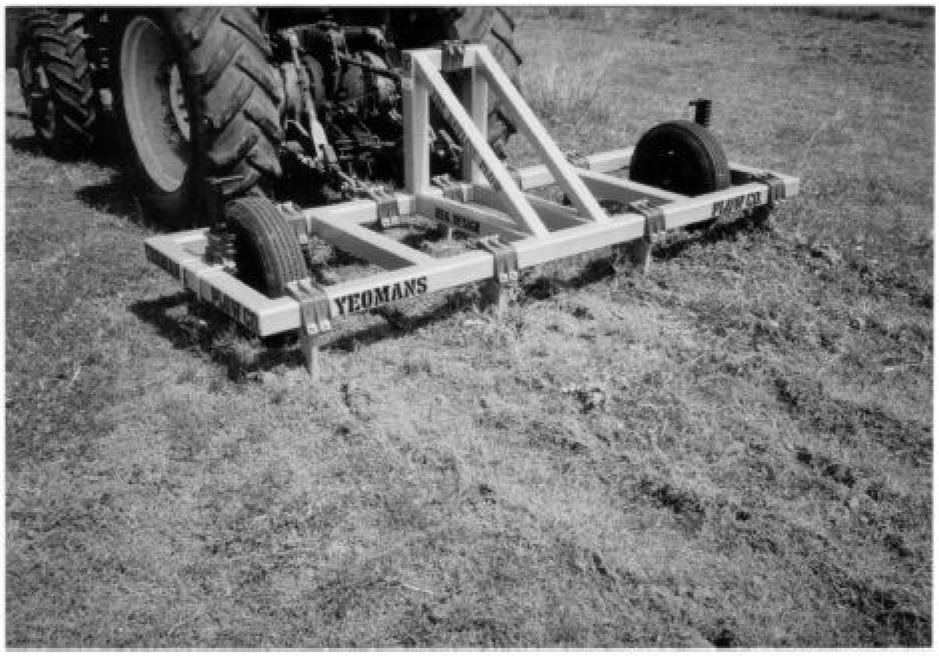


Plate 55 An earlier model Yeomans Plow working near full depth to aerate the soil with 45cm (18”) shanks.

Tyne spacing should be much wider than would be recommended for chisel plows. 24” (600 mm) spacing is 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 re-growth 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.

So many problems are solved simply by increasing soil fertility. (End section by A.J. Yeomans)

E. Practical experience with Keyline

1. North Richmond, N.S.W.

An early experience on our family property in this type of soil making, had as raw material, yellow clay subsoil (from which the three top inches of poor grey soil had been washed away), soft yellow shale rock and a harder blue shale. The original profile had been 50 -75 mm (2 - 3 inches) of grey soil, about 225 mm (9 inches) of yellow subsoil on the hillside ranging to metres (some feet) of the same material in the valley areas. All this was underlain by the harder blue shale that was the immediate geological base of the land. The areas of yellow subsoil clay were associated with the lower parts; the yellow shales with the medium slopes and the blue shale showed on the steeper ridges. The property was west of Sydney and averaged 600 mm (24 inch) annual rainfall.

We cultivated the land around 6 cm (2 to 3 inches) deep with a chisel plough (which does not turn the soil upside-down) equipped with 50 mm (2 inch) chisels spaced 30 cm (12 inches) apart. This first cultivation was done in such a way that the second run with the chisel plough, when made on the Keyline Pattern would form a cross cultivation. The second run was made slightly deeper than the first. A mixture of grass and inoculated legume seed was planted into this rough and lumpy surface together with 125 kg per hectare (one cwt., per acre) of a 50–50 lime-superphosphate mixture. White clover and cocksfoot were included with the planting; both were said not to grow in the region. The weather was warm and the moisture conditions were not critical. The result of this sowing was exceedingly poor. Very few clover plants remained for long after germination, and the grasses were thin and yellow.

This "pasture" was allowed to grow to about 18 cm (seven inches) high before cattle were put on to eat it right off. The area was then cleared of stock and the grass allowed to grow again before being eaten off. The paddocks were finally eaten down in the early autumn by which time the grasses had improved in both colour and growth. A thin sprinkle of white clover and lucerne plants persisted with many plants of subterranean clover. At this stage, which was 12 months from the initial sowing, the pasture was immediately chisel cultivated on the Keyline Pattern working the soil a little deeper than before. The result of this cultivation appeared to be almost complete destruction of the indifferent pasture.

The cultivation revealed a notable change in the soil-material. The lumps were more friable and there was a darkening of the yellow coloured material. Perhaps the most notable change occurred in the harder blue shale, where at first the plants had appeared to be scarcely alive; it seemed impossible for them to persist through to the autumn. There was more fine and dark material while the broken shale and larger shale pieces were a mass of fine cracks, with many of the lumps fretting away and breaking up when touched. The persistence of the various plants was then about equal to that on the yellow areas.

The paddocks were left without stock for the pasture to grow. Regrowth was relatively rapid, the colour was much improved and the change in the clover was notable. While the sub-clover had thickened up, the white clover was now everywhere. Grasses grew taller and thicker. No fertiliser was used then or at any time, during the next ten years.

The pasture was given its time-to-grow after each stocking during the second year when it was cultivated in the autumn as before, but a little deeper. Inspecting the rough surface of this cultivation there was little evidence anywhere of the former yellow shale; the material was now much darker. The formerly blue shale patches looked remarkably like good dark soil. Inspection with the aid of a spade revealed many small earth worms in all the cultivated and aerated “soil”. The soil was dramatically coming to life.

Throughout this second year, the pasture itself had continued to improve at an accelerating rate. Root systems were also deeper and very much thicker everywhere. Many visitors who saw the pasture at the end of the second year believed we would ruin what they then considered good pasture if we cultivated it so drastically again.

The rather spectacular improvement in growth following the apparently destructive cultivation had been seen before. So after the third year the paddocks were again chiselled a little deeper. Throughout the third year the pastures were very good. The rate of recovery from second year chiselling had improved it further.

The fourth year pasture was outstanding. The soil everywhere was then dark and teeming with soil life. There were many more small earth worms, and considerable numbers of larger ones.

From the start of this particular soil development, we had dug samples of soil to examine its progress with a spade every Sunday afternoon and continued this examination for many years.

The cultivation program was completed at the end of the third year when there was an average of 13 cm (five inches) of real soil over all the treated land. The soil continued to deepen and darken as the earth worms increased in numbers and size.

It has been found that the best and cheapest food of all for making soil on the grand scale is the dead roots of good pasture and as it is known how to promote this special organic matter in abundance, a succession of climaxes can be promoted.

2. Beechworth, N-E Victoria.

In May 1971 a TV camera unit, comprising a rural adviser, a cameraman and assistant, was taking movie sequences of projects we had designed in north-eastern Victoria. On one farm, the untreated soil above an irrigation channel was dug up with a spade and discovered to be 75 mm (three inches) deep. The soil peeled off the sub-soil below in a 75 mm (three-inch) thick block carrying the lightbrown earth of the root zone, and not a single root had penetrated into the yellow sub-soil. Soil nearby but below the channel had been ’Keyline pattern cultivated’ once nine weeks earlier with a chisel plow and irrigated immediately afterwards. In this area, wherever the soil was inspected with the spade it was nearly black to a depth of 150 mm (six inches) and carried a heavy root growth with earthworms in evidence. Even the owner of the farm was surprised at this proof of how quickly soil can be made deeper and more fertile.

3. Kiewa, N-E Victoria.

In 1970 in the Kiewa Region of north-eastern Victoria (a southeastern state of Australia), two high ranking officers of the Bureau of Agricultural Economics from Camberra, the seat of the Federal Parliament, inspected many samples of soil that were dug up with a spade. They were there at the request of a Minister of the Federal Parliament to inspect several properties on which these techniques of landscape design had been implemented. The party that accompanied the officers were farmers and graziers of the Kiewa, Ken Yeomans and P. A. Yeomans.

After the officers had been shown several properties, it would be true to say they had become convinced by the inspections and the demonstrations of the efficacy of the water control layouts and other aspects of the development but perhaps not yet of soil making; they were finding it too incredible to believe. We then came the final inspection of their visit.

On this property the owners had double their profit by following only one aspect of Keyline - soil development. Here the officers were finally satisfied when they saw many samples, dug up with a spade, of pasture soil. Some areas of the farm had received only one year of soil development. Adjacent areas had two consecutive years and others the full three years. The officers looked at the soil, and felt it, they pulled it apart, they smelt it and compared it with untreated soil nearby. They became acquainted with the earthworms, which seem to appear from nowhere when the soil is on the improve.

Formerly these pastures were cared for according to the recommended orthodox procedures. However over the past three years no money had been spent on artificial fertilisers and no poison sprays had been used on the pastures. There were no pests to be seen. The money saved added considerably to net profits. So did the greater quantities of better feed that were produced. There were other bonuses: the former worry of bloat had now been removed; there is no sickness in the herd and there are no veterinary bills and a considerable number of man hours have been saved.

Finally, that year they were the third highest in butterfat production for the dairy factory. The two other producers ahead of them were members of the Kiewa Keyline Club who had started their development work one year before them.

They still have their pasture pests, but now the pests are hard to find instead of being in uncounted millions. It became a struggle for a few specimens to survive in a healthy environment. Usually when pasture pests breed to plague proportions they are simply responding to soil and environmental conditions produced by farming practices that are unsound both environmentally and economically.

F. Soil transformation.

The subsoil can be transformed into topsoil. Topsoil can quickly become deeper, darker and far more fertile than that which existed under natural conditions. Soil transformation programs have been repeated on the widest variety of soil-material; on poor soil and on soil not so poor, all over the farming and grazing lands of Australia with similar results.

On many occasions, property owners have started this program and obtained outstanding results such that they were afraid to continue for fear of losing what they had gained from only one chiselling of their old pasture and soil. Yet the soil cannot be improved permanently by only one year's care.

In the book "The Geographical Basis of Keyline", the late J. Macdonald Holmes, Emeritus Professor of Geography at the University of Sydney, made this observation: "The soil he dug for us was a revelation … the three year course of Keyline cultivation, had developed an extra ordinary depth of dark soil just teeming with soil life, while the pastures were thriving."

In review, what had been done was to place the initial soilmaterial in a condition that allowed it to take in rapidly more of the rain that fell, so it would remain in a moist condition with near perfect aeration for long periods. By using artificial fertiliser as a trigger element and lime to provide the alkaline medium so necessary for clovers at germination, plants grew. We had allowed the pasture growing-time to stimulate root-growth.

A rational[19] (rotational) type of grazing system was being practiced on these particular paddocks. Much of this root organic material died soon after the pasture was eaten, so forming food for the soil organisms. So with good living conditions consisting of; moist, warm and well-aerated soil, a plentiful high protein food supply (the recently dead roots of grasses and especially the leguminous clovers), the soil organisms developed rapidly to a climax of soil life. Wind born spores and countless other life forms landed on a new and better soil environment. The society of the living soil was starting to develop.

The changes in the look, smell and feel of a soil which only one such climax of soil life will bring about, is quite dramatic for those who would take notice, but generally no one is looking. Too soon however, the effect on the soil of this one climax will be lost. The soil will drift back slowly to its former condition. However in this particular instance we caused climax to follow climax each time the grass grew up as the roots went down to the limit of the depth of the aerated medium. Each time the well-re-grown pasture, with its new and more fully developed root system was eaten down the majority of the roots again died. Each time the roots died the aerobes of the soil responded to the good living conditions and to the food supply, by breeding frantically. Each climax of soil life development ended with the death of countless millions of the soil inhabitants to play their further part in the enrichment of the soil through death.

The Keyline cultivation done in the early autumn of the first, second and third years was made a little deeper each time. Each cultivation increased the moisture holding capacity and maintained the best possible condition of aeration. So each time the grass roots grew deeper to the full depth of each new cultivation, consequently they increased in quantity as the soil improved rapidly.

1. Succession of climaxes created.

As has been indicated, the soil change brought about by one of these climaxes may not persist for very long, but we had promoted a rapid succession of climaxes.

Each year up to five soil climaxes occurred, each followed the eating down of the well-grown pasture. Three greater climaxes followed each autumn chiselling. The result was and always will be in like conditions, a relatively permanent transformation of the soil.

It is no more necessary to know all about the soil processes in order to manage and improve the soil, than it is to than it is to know all about electricity to switch on the light. We do need to know somewhat more than the obvious items chronicled in this experience. To understand this description more fully we need to know about the climate.

The climate is a mid-temperate zone, 65 Km (40 miles) from the sea. The altitude is from 30 to 90 metres (100 to 300 feet) above sea level with an average annual rainfall of 660 mm (26 inches). There is no reliable incidence to this rainfall since it lies nearly midway between the southern area of strong winter incidence and the northern areas of tropical summer rainfall. There is a wide variation in the yearly rainfall from a low of under 180 mm (seven inches) to a high of nearly 1800 mm (seventy inches). Summer temperatures occasionally reach 38 degrees C. (100 degrees Fahrenheit) with an average maximum in the mid eighties (29 degrees C.). Winters provide only a few heavy frosts.

2. Soil Climate changed.

It has been said that climate is a dominating influence in the formation of natural soil, but here it has been shown that the effect on soil of the regional climate can be manipulated to change the critical soil-climate that can then produce a better soil than the existing one. Even with the climate stated it can be seen that it is necessary to have a sufficient knowledge of, and a feeling for, the principles involved in this soil-making so as to be able to apply the principles to places of different climates and soils.

The question arises; should these techniques be literally followed in areas with an average annual rainfall of 350 mm (14 inches) with a winter incidence, and in another area with 1,270 mm (50 inches) and a summer incidence? The answer to this question is “No”, the cultivation of soil in autumn as we had done could be quite unsuitable in both these other cases.

The purposes of the cultivation are to provide good aeration of a little of the subsoil and all the top soil above it at the time of the year when; following the cultivation, the moisture and warmth conditions are most likely to be best suited to promote a major soil climax. The goal is to produce sufficient consecutive numbers of them, to permanently improve both the soil and the pasture, and soon thereafter the whole landscape.

3. Techniques vary with climate.

Soil influenced by the low winter incidence rainfall would lack moisture in the warm months of early autumn and with the advent of the rains the low temperatures would inhibit climax development. Moreover, if chisel ploughs were used the pasture for winter feed could be depleted by the cultivation process and this may also worsen the conditions of over-wet and boggy soil. However in these circumstances a cultivation immediately after the first eating out of one or two paddocks in spring may promote the success of these dynamic principles.

In the somewhat warmer climate with its 1,275 mm (50 inches) of predominantly summer rains -- a spring or autumn start on a soil improvement program may be pointless. Of course, the best time to complete the first “soil aeration” could be the day before it rains. But who knows when it is going to rain? However a paddock or two may be devoid of grass and be so dry that there can be no further growth until rain falls. Therefore the cultivation will have been right for these paddocks whenever it rains.

Are there any changes in procedures necessary for differing soils, as well as those that are be dictated by the various climates? There are two principal aspects of soil to be considered, one that is readily visible and the other invisible.

Firstly, it is obvious whether the surface is a soil (no matter how poor), or merely a basic soil-material. If it is soil, then there are some aspects of the cultivation that are affected or governed by the features of the soil. Considerable areas of agricultural Australia are covered by only 50 mm (two inches) of top soil that is alive. There are also parts, notably in the poorer granite belts, where the depth of the living soil is little more than a smear of darker colour over the very light coloured material below. Some soil is relatively infertile and low producing even though they are deep. Each of these soils require a somewhat different treatment to that given to our soil-material.

Secondly, the unseen relates to the soil’s necessary mineral elements of fertility and their availability. Some of these elements may be in such short supply that the health of plants and the animals, forced to live there, is impossible. On the other hand all the minerals may be in adequate or even plentiful supply but still be useless to plants by being unavailable in their existing form. Unavailable minerals may be made available by being processed biologically by soil organisms. It is in enhancing these natural processes that the farmer and grazier can lift the health and productivity of his country.

XXII. TRUTHS ON TRACE ELEMENTS

Like all aspects of agriculture one factor affects others. Mineral deficiencies, if any in agricultural soils including those needed in only trace proportions, are usually known in a general way, by departmental advisers or Agricultural Department extension services. These minerals would need to be added as part of the trigger elements at the commencement of an improvement program, but once the soil forming process is satisfactorily begun it may never be needed again.

Many areas which are reputed to be short of one or several of these mineral necessities, do contain some of them. However the minerals may be present in an unavailable form so their natural presence is sometimes disguised. When applied as recommended they nearly always show an improvement in the rate and colour of growth. The response of plants to an added mineral or added trace element does not in any sense prove its need or that the soil is lacking in it. This fact is often not even suspected by many extension workers or is completely ignored by any with a vested commercial interest in the supply of the products.

Side by side with our experience of sub-soil and soft rock conversion to fertile soil, another area was treated in the same manner except in one respect. Every trace element recommended for any area extending well beyond our soil zone and climatic setting was added with the seeding. As would be expected, the first growth from this trial was better than the other. Firstly and most notably, the colour of the pasture species was good by comparison. Secondly, the rate and the thickness of the growth was a little improved. Both these effects showed for a little over a year. But about fifteen months after the original application, there was no difference in the results to be seen between the two programs.

I[20] recounted this experience later to two separate groups of C.S.I.R.O. scientists during their visits to my property. Naturally they wanted to see for themselves and after it had been pointed out that the “trace element paddock” was one of four visible from the discussion point, an inspection was made. The inspection included taking many samples with a spade, from various paddocks. At the end of a two hour walk no one was prepared to make a firm selection of any paddock as the one treated with all elements.

On the second of these occasions the late Sir Ian Clunies Ross was the leader of the party, which included Dr. John Anderson, the trace element discoverer and research authority. He was as well known and respected overseas for his work in this field, as he is in Australia.

These events are recounted here to add emphasis the fact that plant response to applied mineral fertilisers is by not proof of their deficiency in the soil; just a lack of availability.

A. Availability of primary minerals

The "soil" in this examination which was not treated with trace elements showed by the poor colour of the grasses and other signs in the first year, that there were deficiencies in the soil, but less than two years later there were no plants with these deficiency signs. The course of the soil making program, by triggering off vital soil processes, had changed the availability of the minerals present in the soil and sub-soil into forms suitable for plant nutrition. Never-theless it may be wise to add trace and other minerals to the "trigger" fertiliser at the start of such a program. Indeed it could be safer to add them since had the conditions of climate been somewhat worse, any means which may ensure a better start could play a critical role.

The whole story illustrates one of the widest held fallacies of both official and commercial agriculture, namely, that if deficiency signs in crops and acid reaction tests of the soil indicate one or more deficiencies, then there is only one corrective course to pursue; it is assumed that the particular minerals must be added artificially to the soil.

The diluted acids used in soil tests do not disclose the great truth that soil minerals can be, at one and the same time (1) insoluble in both water and the test acids and (2) available to the plants by other soil processes. Indeed if nutrient minerals could not be both "insoluble and yet available" they must have all been leached from any worthwhile agricultural soil long ago, since only the lack of rainfall would have allowed them to be retained in the surface soil or shallower sub-soils.

Soil minerals may be absent from some shallow top-soil yet be present in an adequate but presently unavailable supply only three to five centimetres (an inch or two) lower down in the sub-soil.

When plants cannot obtain their proper mineral requirements, there may be two means and not only one by which they can be supplied. (1) Minerals may be imported to the farm and "added"; in a dry or liquid or gaseous state. (2) Minerals may be "made available", by mechanical or biological treatment of the soils which have always contained them but now in a locked-up form. The mechanical treatment is intended to enhance a biological process so plant and stock management practices must play a vital role.

Because of the tremendous importance of this particular factor of soil improvement it is worthwhile pursuing this matter further by relating two other aspects of these particular visits by the scientists.

During one discussion I was asked if I believed in trace element additions to the soil. My reply was in the affirmative, but I suggested that from the present manner of their use it could not be known whether they were unavailable but actually present, or absent altogether from a particular soil. Clearly when the "missing" elements had been determined by trials and then added, the results were quite spectacular. But could the trace elements be made available at less cost by other more soil beneficial means?

Sir Ian Clunies Ross asked how I would suggest the work be done. My reply was on these lines: Practically all soils relevant to the discussion were poor or depleted. Nearly all Australian aged soils were "soils-in-decline" and long past the stage of their highest fertility. Therefore it should first be determined what each soil could do for itself in the way of improvement, after treatment and management that was aimed solely at improving the moisture-air relationship in each soil, or, improving the soil-climate.

All soil men highlight the importance of soil aeration. But by comparison the Keyline treatment of ours was truly a very drastic soil aeration. For instance, with pasture on 5 centimetres of soil (a twoinch soil), we would literally tear it to pieces with a chisel plough but digging not more than 7 to 8 cm (three inches) deep. This cultivation would be timed to suit warmth and moisture conditions. Then the soil and pasture would be managed as we had done before by giving the pasture its time to grow up after each eating off. The same timed cultivation once each year for three years would be given while continuing this same pasture management.

At the end of this time the soil would have available to plants at least a goodly portion of the minerals which it did contain. On this "climate" improved soil all the trace element tests and experiments could be conducted. My opinion was that these tests would then tell the truth.

In support of this program there would be no need to delay any pasture improvement work which now involves the application of trace elements. But in as many of these cases as possible small areas, not "plots" should be kept free of added elements and subjected to the “soil-climate” treatment only. Sir Ian at this juncture remarked to Dr. J. Anderson that they should do some of their trace element experiments over again and on these lines.

B. C.S.I.R.O. attitude to Keyline

After this visit Sir Ian continued to display his interest in Keyline generally, to the extent that I was asked if I would assist with the Keyline planning and consulting if the C.S.I.R.O. allocated for Keyline development, an area of 243 hectares (600 acres) on the new land to which the Canberra experimental farm was to be moved. My full co-operation, to which only one condition was applied, was accepted by Sir Ian. The condition was that no soil conservation philosophy or practise should be allowed to intrude on the selected area so that the experiment could also function in the nature of a “test-of-Keyline”; surface and gully erosion which were both present on this land, would be “cured” as they are in Keyline, only as an incidental to the Keyline work.

I visited the selected area in company with officers of the C.S.I.R.O. in Canberra on more than one occasion. Unfortunately the untimely death of Sir Ian prevented the Keyline project from happening.

On another occasion a C.S.I.R.O. officer with a group visiting our property, asked me what I would do to solve a problem in the case of an area of 1,620 hectares (4,000 acres) of very poor soils which had been “pasture improved”. The pasture improvement program used was the now orthodox one, but when the program started these were new techniques. Clovers and grasses were sown and superphosphate was spread year after year for many years. Initially very few sheep could be carried on the unimproved land but soon it carried 2.5 sheep per hectare (a sheep to the acre). This had never before been achieved on such country.

The carrying capacity continued to rise as the grazier prospered; and so a carrying capacity of 12 sheep per hectare (five sheep to the acre) was reached. This was one of the first properties in the particular state where the recommendations of scientists for pasture improvement had been faithfully and enthusiastically followed. The outstanding success here had given pasture improvements a new impetus among sheep graziers in the surrounding area.

After a number of years the now consistently high wool clip suddenly and unaccountably dropped by 10 bales in one year. The grazier, though baffled, was not unduly concerned by this one year’s reduced clip. But within the next year the ability of the improved pasture to carry sheep utterly collapsed. Large numbers of sheep were dying which necessitated the quick removal of all the remaining sheep from the "improved" country. Apparently the pastures still looked well and the soil of the pasture was perhaps five centimetres (two inches) deep and very dark where originally it had been a very light colour.

It seemed to me that the yearly top-dressing of superphosphate, by off-setting a phosphate deficiency had, with the clovers and general stocking management, provided a basis for a rapid, but unbalanced, soil change. It had enabled the pasture to use the mineral nutrient elements of the soil, but only from the top few centimetres (inch or two). Eventually the available supply of one or more necessary nutritional elements was consumed. Then, since an essential element in short supply restricts the plant's use of other elements, the shortage of the missing factor had produced an impoverished pasture which caused the serious malnutrition from which the sheep died.

However, since the pasture had been able to support the breeding of increasing numbers of sheep for so long, the now missing element must have been previously contained at least in the top few centimetres (inch or so) of the soil. Therefore, it must be considered unlikely that the now extracted mineral had existed only in the thin surface layer and so it would be still in some sort of supply immediately below the present top-soil. Moreover the type of pasture management, with the yearly dressing of superphosphate which was spread on the ground without any disturbance of the soil, would also have inevitably resulted in faulty soil aeration which would worsen any other bad effect.

Scientific tests were carried out to try to determine what the missing minerals were, but they had not yet provided the solution to the problem, which was immediate and urgent. Of course, once the missing elements were replaced then the corrective effects could be relatively rapid.

My experience suggested that the farmer should follow the Keyline methods, covered in this book. So giving consideration to the fact that the weather was still warm and soil moisture was satisfactory and could improve.

The immediate action recommended, in the improved pasture area, was that the soil be aerated (loosened) using a chisel plough, preferably on the Keyline pattern, and not more than about eight centimetres (three inches) deep. This depth of cultivation would extend no more than a few centimetres (an inch) into the sub-soil. Soil reactions under such condition could be very rapid indeed.

The expected results from this drastic, aerating cultivation would be:

(1) The rapid development of the soil-life toward a climax. This would be sustained in the warm moist and aerated soil by the abundant organic material present near the surface.

(2) The soil organisms would be biologically processing fresh soil material in both the shallow top soil and in the newly loosened subsoil. (3) Humus would be produced by these soil organisms. The humus would include, in an available form, the minerals now in critically short supply in the top-soil.

(4) The first re-growth of pasture would send roots down into the aerated and moist sub-soil and the effect of this would be the transformation of some of the inert sub-soil into biologically active top soil.

(5) The pasture could be affected to the extent of at least partially remedying the deficiency in the first re-growth after the treatment.

The owner of this property was in the group and his comment was, “That’s what we will do!”. There has been no further trouble on this particular property although I did not see the grazier again for 10 years.

C. Common misunderstandings on plant nutrition.

Misunderstandings about plant nutrient supplies can be linked to a defeatist attitude toward soil fertility.

Although mineral deficiencies in plants may be solved on site by deepening of the living soil and improving the soil’s biological fertility, the most common belief is that the problem must be solved by minerals imported onto the site.

It is my conviction that any lasting benefit from purchased minerals will depend on either their continued use or the dynamic ability of a living soil to produce its own mineral rich humus.

Part of the confusion is because the processes in living soil are not understood. The processes that prepare minerals for inclusion in normal plant nutrition are biological and complex. As too is the method by which the plant then selectively takes in it’s particular nutrient requirement. These processes do not always conform to contemporary expectations based on chemistry experiments in the laboratory. Nor do explanations based on these experiments represent the true facts of the soil-plant nutrition processes.

The early and still too general belief is that the water solubility of fertilisers is the measure of their feeding value to plants. Despite the fact that some water soluble fertilisers are quickly washed out of the soil while others become insoluble and theoretically useless. The flow of water moving from the soil into the plant roots, through the plant stems, branches and leaves which transpire into the atmosphere, is not a stream which carries the nutrients for the plant.

1. Some American experience

Dr William A. Albrecht, Emeritus Professor of Soils at the University of Missouri, whom I visited at his University in 1958, told me of experiments and tests which showed that plant nutrition could continue normally when there was no transpiration of water from the plant and this “stream” had stopped. Further, that plant nutrients could move into the plant from the soil or visa versa quite independently of the water movements in the plant. Here are his own words on these two matters:

“As the first fact, plants will grow and their nutrients will move normally from the soil into the roots without the evaporation of water from the leaves. A potted plant, enclosed in a water saturated atmosphere with carbon dioxide under a glass bell-jar in the light, will grow normally. This fact tells us that while the transpiration stream is halted because the saturated atmosphere will not take any water of evaporation, the fertility elements are, nevertheless, flowing into the plant from the soil. In research at the Missouri Station, some soybean plants were grown on soils of such low saturation of the clay by calcium, that the total of nitrogen, phosphorus and potassium in the complete crop of tops and roots were less than those of the planted seed. Such facts tell us that the fertility elements may flow out of the roots, or in the reverse direction of the flow of the transpiration stream of moisture.”

Four very interesting days were spent with Dr. Albrecht on the Missouri Station. It is the second oldest Agricultural Research Station in the world, only Rothamsted in England being older. The important aspect of these discussions on soil and plant nutrition is whether a sufficient appreciation can be gained of the soil processes and plant nutrition, to cause us to reorient our thinking about soil management.

XXIII. ROTHAMSTED RE - VISITED

Later in this chapter is a fairly detailed report of one of the experiments done at the world renowned Rothamsted Experimental Station, in Harpendon, Herts., England. The report adds further emphasis to the soil's capacity for "self improvement". The improvement results principally from altered relationships between air and water in the soil.

A. Nature in the picture

> "When nature puts different species of plant and animal life in different places so that nourishing grasses grow in some areas, trees and forests in others, she is demonstrating the differing plant-nourishing qualities that exist in the various soils. The natural array of the various interrelated life forms are informing us that the soil of each region is best suited to supplying the needs of the specific plant and animal life which thrive in that region. Each of the natural crops (plant and animal) represents a survival of the fittest, determined basically, if there are no disturbing factors, by what the local soil provides as nutrients." (Albrecht)

Only some of these natural soils provide adequate proteins for plants to provide for the complete health and well being of man. Therefore, when man pushes out from these regions of complete soils to other's not naturally suited to produce quality protein, he needs to improve the fertility of the soils. When such natural soils are deficient in the necessary array of minerals or when soils are depleted; when "self improvement" of the soil has failed to make available and/or bring up from below, these minerals, then they must be added. For sustained fertility they should be in the natural form such as limestone rock, phosphate rock, potash rock and the other minerals in this natural form. Artificial soluble fertilisers can only act as starters or trigger elements since, if they continue in soluble form in the soil the bulk of them is soon washed away or, if the rainfall is insufficient to wash them out, the seedlings planted with these "artificials" would soon be "salted to death".

Any form of chemical which could not have become a part of fertile soil in nature must now be suspect as an anti-health factor for all life that is dependent on the soil. So little is known of the biological processes that start in the soil and finish in the metabolism of the human body and are affected by unnatural chemicals, that the soil must be continuously guarded.

Soil fertility and its cleanliness from man-made unnatural chemicals is now a matter of interest for everyone.

Referring again to the proposition that crucial mineral elements of complete soil fertility have two possible avenues of return to the soil, either or both of which may be used, a record of an experience during my visits to the Rothamsted Experimental Station, in Harpendon, Herts., England is relevant.

During the first of two visits in 1958, reference had been made on the Station to the Rothamsted "U" which seemed to have some relationship to the growing of wheat. Later, I[21] came to understand it had to do with the recording of the wheat yields on the Broadbalk strips where this grain had been grown under conditions involving various fertiliser applications on the same land, for over 100 years.

The general purpose of the experiment was to determine over a long period of years, the manurial requirements of wheat by testing farmyard manure alone, then with a number of combinations of ash constituents of crops, compounds of phosphorus, potassium, sodium, magnesium, together with several forms of nitrogen compounds.

In order to graphically illustrate the yields from the varying soil treatments, the yield of each of the strips was represented on a framed board by a small sheaf of ripened wheat. The sheaf included the stalks and the grain heads. The stalks and grain heads combined varied in length so as to illustrate graphically the yield from each strip. The outline of the heads made a lop-sided U.

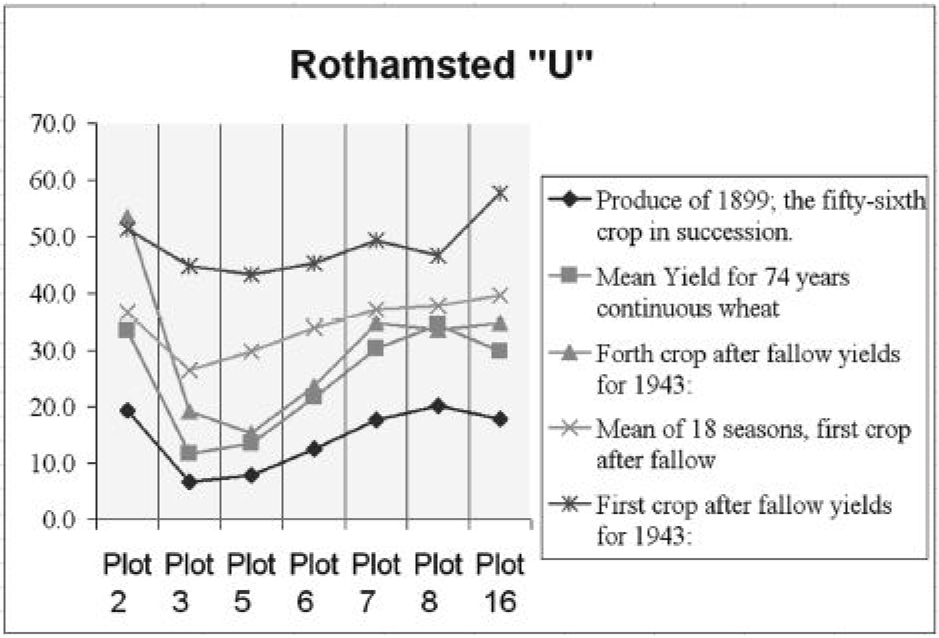
Before proceeding further; the history of the famous Broadbalk experiment falls into two sections. Firstly from 1843 to 1925, when the wheat crop was grown continuously over the whole field, and secondly, from 1926, when in order to deal with the increasing problem of weed infestation, a system of fallowing was introduced. The Broadbalk experiment consists of seventeen long parallel strips of land each half an acre (2,020 square metres) in area, running the length of the field, separated by narrow pathways which are kept clean by frequent cultivations.

To maintain the continuity of cropping with the introduction of a fallow plot for weed control, the field was divided across the strips or plots in 1925, into five equal sections so that while one part was fallowed English fashion, there would be four sections under crop every year.

The purpose of the fallow in the drier marginal wheat lands of Australia, is to promote storage in the soil of extra water from rainfall so that a good crop can be produced later. Very often the fallow is the only chance for a good following crop, since it may grow one crop of wheat from two years' rainfall. However at Rothamsted the fallow each five years has, as its sole objective, the overcoming of the weed problem. Rainfall conditions are such that extra retention of moisture in the soil is not considered to be a factor in wheat production.

In the present fallow system, introduced in 1931, one fifth of the field across all the plots is fallowed each year. The yields for each of the manurial treatments from years 1 - 4 after fallow have been obtained. (From "The Guide to the Experimental Farms", a Rothamsted Experimental Station Publication.)

There were of course many such charts. The unique shape of the Rothamsted U is the outline of the seven grain heads of the sheaves, which, according to their height, represent the relative yields for each variety of manure treatment.



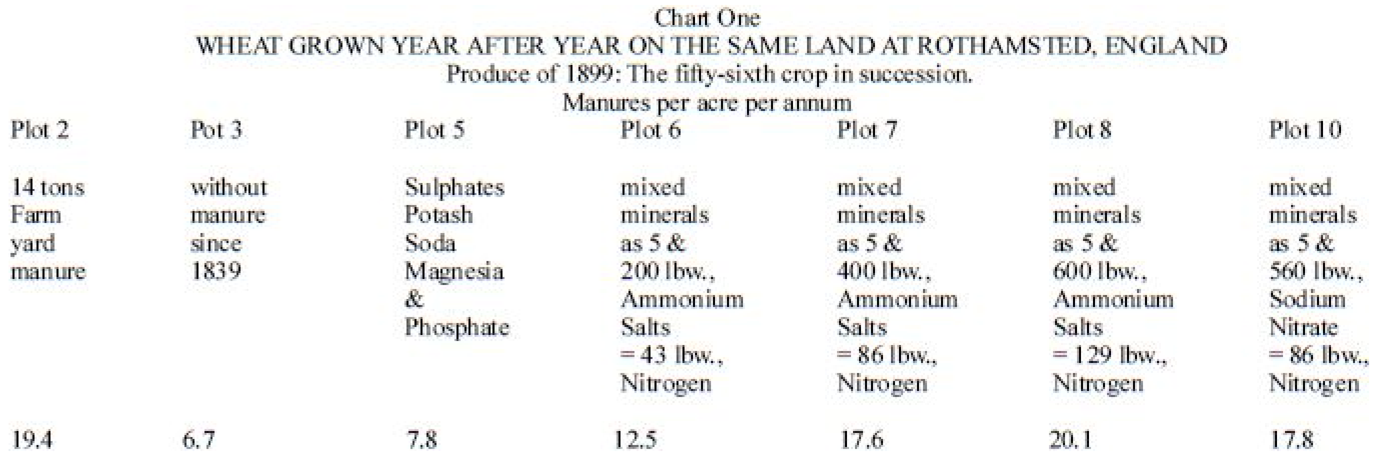


Chart One

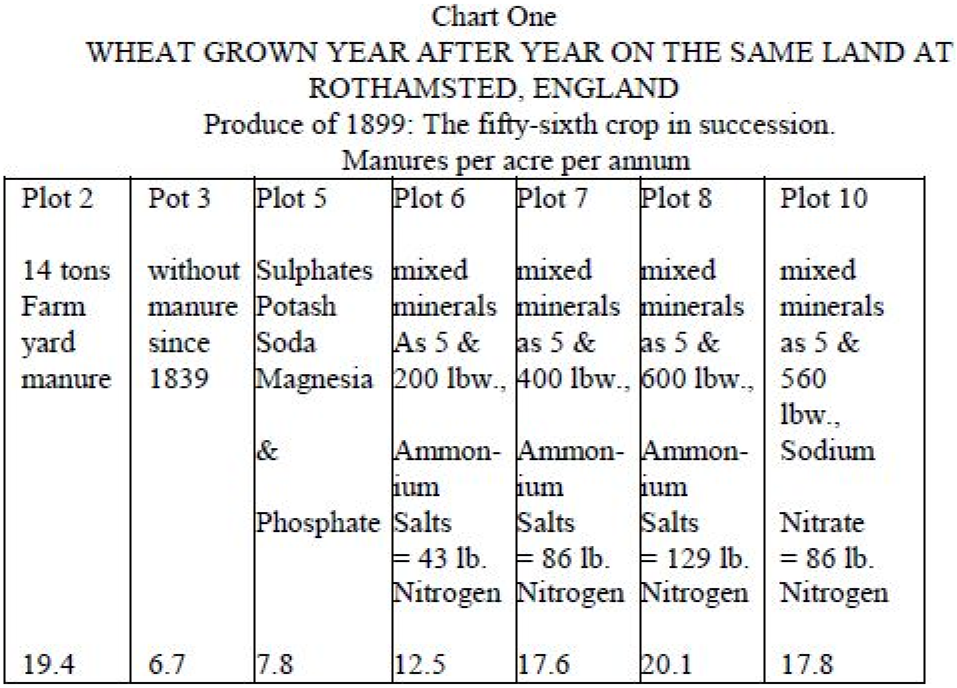
WHEAT GROWN YEAR AFTER YEAR ON THE SAME LAND AT ROTHAMSTED, ENGLAND

Produce of 1899: The fifty-sixth crop in succession.

Manures per acre per annum

Plot 2	Pot 3	Plot 5	Plot 6	Plot 7	Plot 8	Plot 10
14 tons Farm yard manure	without manure since 1839	Sulphates Potash Soda Magnesia & Phosphate	mixed minerals as 5 & 200 lbw., Ammonium Salts = 43 lbw., Nitrogen	mixed minerals as 5 & 400 lbw., Ammonium Salts = 86 lbw., Nitrogen	mixed minerals as 5 & 600 lbw., Ammonium Salts = 129 lbw., Nitrogen	mixed minerals as 5 & 560 lbw., Sodium Nitrate = 86 lbw., Nitrogen
19.4	6.7	7.8	12.5	17.6	20.1	17.8

The wheat yields are not tabulated on this chart of 1899, but the average yield from 1852–1925 in bushels of wheat for each plot is included below the respective plots of the chart.



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19.4	6.7	7.8	12.5	17.6	20.1	17.8

The data in the next paragraph has been converted to metric, the original data (which matches the chart) is in the following paragraph shown in *italics*. Also Chart One results are repeated at the bottom of Chart Three.

Plot 2, first on the left in the chart with its 35.2 tonnes per hectare per year, yields higher than Plot 5 (third from left) with its five added minerals, and higher than Plot 6 (centre) with its additional 225 kg/ha of Ammonium Salts (48 kg/ha nitrogen) and minerals as in Plot 5, and again higher than Plot 7 with the same added minerals as Plot 5 and 202 kg/ha of Ammonium Salts (96 kg/ha nitrogen). However when 675 kg/ha of Ammonium Salts (145 kg/ha nitrogen) is added to the minerals common to Plot 5, 6, and 7, Plot 8 (second from right) exceeds the production of the farmyard manure, Plot 2.

[*Original Imperial data*

Plot 2, first on the left in the chart with its 14 tons of farmyard manure per acre per year, yields higher than Plot 5 (third from left) with its five added minerals, and higher than Plot 6 (centre) with its additional 200 lbw., of Ammonium Salts (43 lbw., nitrogen) and minerals as in Plot 5, and again higher than Plot 7 with the same added minerals as Plot 5 and 400 lbw., of Ammonium Salts (86 lbw., nitrogen). However when 600 lbw., of Ammonium Salts (129 lbw., nitrogen) is added to the minerals common to Plot 5, 6, and 7, Plot 8 (second from right) exceeds the production of the farmyard manure, Plot 2.]

Plot 3 (second from left) has been without manure (fertiliser) since 1839 and therefore 60 years without manure at the time of this Rothamsted U chart dated 1899. Plot 3 consistently yields the lowest but only a little lower than Plot 5 with its full quota of added minerals.

Whatever the effects or processes involved in the soil induced by the fallow year, it has a most extraordinary influence on the production of wheat in the year following the fallow. The Rothamsted U is completely altered.

The following comment about the fallow is from “The Guide to the Experimental Farms”:

> “In each year, therefore, the yields of every treatment for the first, second, third and fourth years after fallow are obtained. During the course of the season the fallow section is ploughed two or three times, spring-tyne harrowed, rolled and harrowed, and run over with the thistle bar several times.”

The detail of the fallow treatment is given last in these particulars because these are the most significant causes of change.

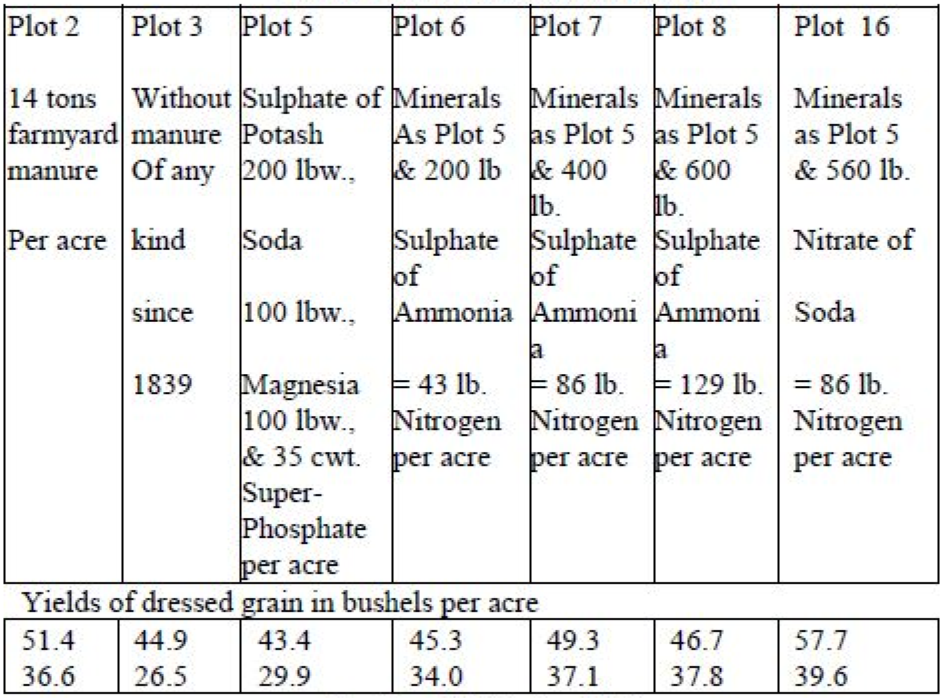
What, for instance, in these procedures could possibly explain why the section of Plot 3 in the fourth year after fallow produced 780 kg/ha (the average from 1852 to 1925, the start of fallowing was 447 kg/ha) while a part of the same plot in the same year but on the first year after fallow section produced 2,994 kg/ha, and when for 94 years this plot had been producing wheat with no manure of any kind whatsoever? **Why, on the first year after fallow, did the “nothing ever” Plot 3 far out-produce the sections of Plots 5, 6, 7 and 8 section with all their added fertilisers?**

[*Original Imperial data: What, for instance, in these procedures could possibly explain why the section of Plot 3 in the fourth year after fallow produced 11.7 bushels (the average from 1852 to 1925, the start of fallowing was 6.7) while a part of the same plot in the same year but on the first year after fallow section produced 44.9 bushels, and when for 94 years this plot had been producing wheat with no manure of any kind whatsoever? Why again did not the sections of Plots 5, 6, 7 and 8 on the first year after fallow section with their added fertilisers, far out-produce the “nothing ever” Plot 3?*]

Explaining the reasons for the results revealed in these charts may be speculative but the facts should not be ignored.

Chart Two

FIRST CROP AFTER FALLOW



Plot 2	Plot 3	Plot 5	Plot 6	Plot 7	Plot 8	Plot 16
14 tons farmyard manure Per acre	Without manure Of any kind since 1839	Sulphate of Potash 200 lbw., Soda 100 lbw., Magnesia 100 lbw., & 35 cwt. Super-Phosphate per acre	Minerals As Plot 5 & 200 lb Sulphate of Ammonia = 43 lb. Nitrogen per acre	Minerals as Plot 5 & 400 lb. Sulphate of Ammonia = 86 lb. Nitrogen per acre	Minerals as Plot 5 & 600 lb. Sulphate of Ammonia = 129 lb. Nitrogen per acre	Minerals as Plot 5 & 560 lb. Nitrate of Soda = 86 lb. Nitrogen per acre

Yields of dressed grain in bushels per acre

51.4	44.9	43.4	45.3	49.3	46.7	57.7
36.6	26.5	29.9	34.0	37.1	37.8	39.6

Top Row Yields for 1943:
Bottom Row Mean of 18 seasons, first crop after fallow

In chart two: “FIRST CROP AFTER FALLOW”; the Plot 3 result is about equal to the results obtained from the continuous application of ample quantities of minerals on Plot 5, 6, 7, 8 and 16, plus 225 kg/ha (200 lbw., per acre) of ammonium sulphate in their first crop after fallow. But the average result for 74 years, 34.5 bushels, from all mineral plus the maximum amount of nitrogen in 674 kg/ha (600 lbw., per acre) of ammonium sulphate (Plot 8), is much less than the Plot 3 result in its first crop after fallow.

The result from the fallow and no fertiliser is better than would be the result without the fallow, with all minerals and nitrogen added.

Is the result from Plot 8 produced by the added minerals plus nitrogen or does the fertiliser act as a starter only? Perhaps the greater amount of the minerals in the crop coming from the soil is somehow being processed and made available (1) by the nitrogen or (2) by some results from the initial vigorous growth of the roots themselves or (3) other soil processes not obvious or understood.

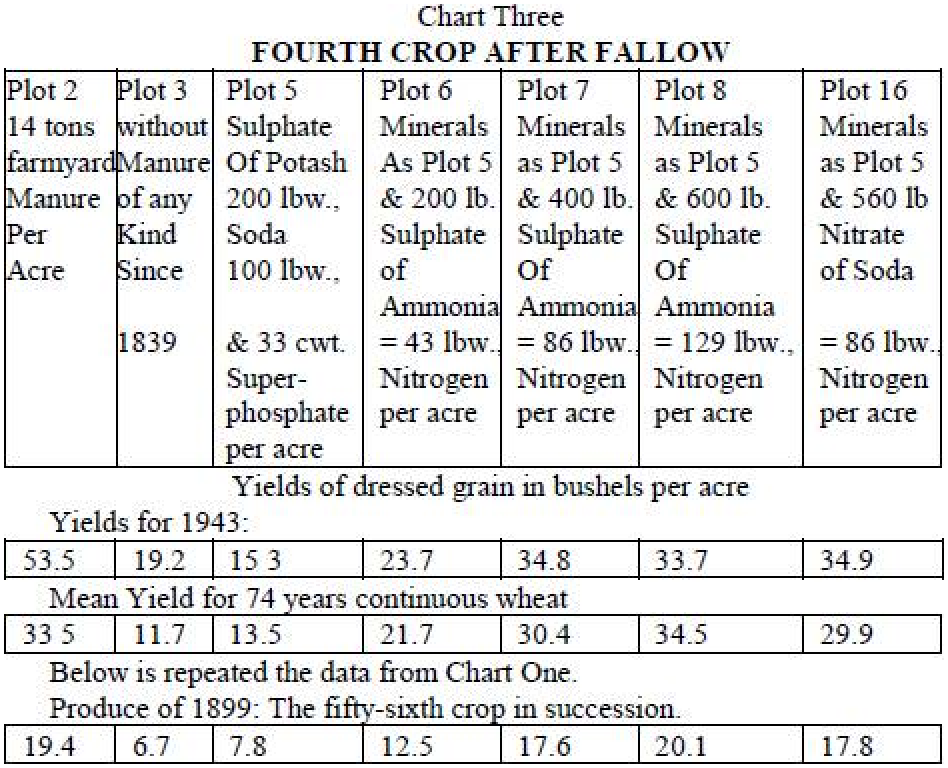


Chart Three

FOURTH CROP AFTER FALLOW

Plot 2 14 tons farmyard Manure Per Acre	Plot 3 without Manure of any Kind Since 1839	Plot 5 Sulphate Of Potash 200 lbw., Soda 100 lbw., & 33 cwt. Super-phosphate per acre	Plot 6 Minerals As Plot 5 & 200 lb. Sulphate of Ammonia = 43 lbw. Nitrogen per acre	Plot 7 Minerals as Plot 5 & 400 lb. Sulphate Of Ammonia = 86 lbw. Nitrogen per acre	Plot 8 Minerals as Plot 5 & 600 lb. Sulphate Of Ammonia = 129 lbw., Nitrogen per acre	Plot 16 Minerals as Plot 5 & 560 lb Nitrate of Soda = 86 lbw. Nitrogen per acre

Yields of dressed grain in bushels per acre

Yields for 1943:

53.5	19.2	15 3	23.7	34.8	33.7	34.9

Mean Yield for 74 years continuous wheat

33 5	11.7	13.5	21.7	30.4	34.5	29.9

Below is repeated the data from Chart One.

Produce of 1899: The fifty-sixth crop in succession.

19.4	6.7	7.8	12.5	17.6	20.1	17.8

No attempt has been made here to present a complete study of the soil. For those wanting to learn of the science of soil, there are ample good books on the subject from “An Agricultural Testament” by Sir Albert Howard to “The World of the Soil” by Sir John Russell. The C.S.I.R.O. has issued bulletins on soil and the Agriculture Departments can further advise on appropriate reading material.

From our observations it seems likely that no natural soil has remained highly fertile, that is, always capable of producing complete and wholesome food for mankind and his animals. Among other things, fertile soil depends on the life within it and this soil life, like all life forms and communities, progresses through normal development stages, as depicted by the “bell” curve of life. Firstly, there is the very slow progression which is followed by a more rapid development that leads to the climax period and then inevitably slows down and ceases. The tide turns downward. Most present soils all over the world are therefore soils-in-decline. It seems likely that only under the care of intelligent man can poor soils, be quickly regenerated and maintained in a fertile condition.

XXIV. WATER HARVESTING - PART OF KEYLINE.

The historical background of Keyline dates from 1943 when we first took possession of “Yobarnie” near Richmond, New South Wales, about 65 Km (40 miles) from Sydney. By 1945 we had built many dams and had a considerable area of land under irrigation.

Referring to the period 1945 to 1947 the late J. Macdonald Holmes, Professor Emeritus of Geography of the University of Sydney, said in “The Geographical Basis of Keyline” (page 38): “This extensive irrigation on ’Yobarnie’, embracing many variations of both spray and flood irrigation, was the first carried out on the undulating land in or around the County of Cumberland, and from farm-stored water. There is no doubt that the early ’Yobarnie’ techniques of off-setting the limitation of a catchment by constructing feeder or water-conservation drains to tap the run-off from wider areas outside the valley catchment, and then storing that water in a dam, have had a profound influence throughout Australia. This is shown by the growing interest of farmers in the development of their own water resources for irrigation purposes, and in the reorganisation of their properties as a whole.”

Students from colleges and universities with their professors and teachers have visited our property regularly since 1945. Our methods of farm water resource development for irrigation purposes were then unique and we had many country visitors. Keyline programs have been increasingly brought into school, agricultural college and university studies ever since.

During the mid 1940’s when we first started to spray-irrigate from farm dams on “Yobarnie” onto what are often referred to as “hill lands”, there was in general only one class of farm land irrigated (outside the land of Government irrigation districts). This was the relatively small areas of good alluvial soil contained on the flats of the creeks and rivers, where water was pumped directly from the stream, or indirectly from wells and bores near the river. Spray irrigation was thus used for the production of vegetables and orchard crops. Considerable quantities of fodder crops and lucerne were also grown.

The direct objective of our irrigation on “Yobarnie” was to produce feed for beef cattle raising. At the same time we were endeavouring to improve the fertility of all our soil. The pastures produced by spray-irrigation were found to be expensive for this type of enterprise. Therefore other methods of irrigation were investigated. These included irrigation from contour furrows and “wild flood” irrigation. Since the dams were equipped with pipelines through the walls we were able to do most of this work by gravity, which avoided pumping. Our spray irrigation equipment delivered up to thirty litres of water per second (0.87 ML per 8 hours = 400 gallons per minute = 24,000 gallons per hour), so we could irrigate up to a maximum of 1.7 hectares (four acres) per 8 hour day supplying 50 mm (two inches) of water with each system. The first lock-pipes we placed through our dam walls were 100 mm (four inches) in diameter and the irrigation rate from our earliest gravity flow system was little faster than spray irrigation.

So we decided on a drastic step. We emptied a dam, cut the wall, laid a larger pipe and reconstructed the wall over it. These experiments led to the use of still larger pipes and it was found that a limit for one man operation was reached with a flow of 437.5 l/s (350,000 gallons per hour)[22], compared with the general rate, of spray-irrigation plants at the time, of from 15 l/s to 22.5 l/s (12,000 to 18,000 gallons per hour). Thus the cost significance is very apparent since both undertakings are serviced by one operator. The buried main lines of our spray-irrigation set-up have not been used since 1948.

Briefly, our original set-up comprised of several valley dams and a creek dam. The dams in the primary valleys were all filled with the aid of channels which diverted rainfall run-off water from the farm into the dams. We originally referred to the water diversion channels as “feeder drains” or “water conservation drains”. A pump and engine was set up at the creek dam and also delivered water for spray irrigation via about 2 Km (7,000 feet) of underground mains, as well as filling a ring dam.

Prof. H. J. Geddes, Garland Senior Lecturer in Animal Husbandry at the University of Sydney, had managed the university farm at Badgery’s Creek since 1942. He visited our property at Richmond in August 1952 and the first farm dam for irrigation purposes was constructed at Badgery’s Creek soon after, before the end of the same year.

The term “water harvesting” was used in 1953 to describe spray irrigation from farm stored water at the University of Sydney’s McGarvie Smith Animal Husbandry farm at Badgery’s Creek.

Badgery’s Creek became, very obviously, the first official implementation of a significant aspects of Keyline design. Because the project was done in the context of a university experiment farm it provided an impetus to the community awakening to the significance of the wasted water resources that exist on Australian land and it has directed further attention to the possibilities of the development of farm water resources for irrigation purposes.

Essentially the Badgery's Creek work embraced the construction of dams in the primary valleys of the farm and the building of diversion channels to collect rainfall run-off to fill them. The water thus stored was used to spray-irrigate pastures for a dairy herd.

The spray irrigation project at Badgery's Creek was located within the relatively high-cost, high-return economy of a dairy farm situated in the milk-zone of the Sydney area. The financial incentive was to reduce the expenditure on concentrates by making use of sprayirrigated pasture and other irrigated crops. Later, ring dams were added to increase the water supply and they were filled by pumping from the flood flow of Badgery's Creek itself. These later dams were first referred to as turkey nest dams. Some general subsidiary techniques were used such as strip grazing.

The Keyline approach has always been firstly, to make better use of direct rainfall for both increased production and soil improvement and secondly, to store run-off water in farm dams for irrigation.

On the other hand the early object at Badgery's Creek was to leave the land above the diversion channels or water harvesting drains in an unimproved condition so that run-off would not be reduced. The increased run-off was used to fill the lower dams which were to be used for spray irrigation. If the dams happened to be full the induced run off was lost from the farm. In this was revealed a decided change in emphasis perhaps which was perhaps partially attributable to the difference in the enterprises, beef raising and milk production.

From 1953 this spray irrigation system at Badgery's Creek received a great deal of publicity. The appearance of the sprayirrigated pastures, by comparison with the very poor natural grass of the immediately surrounding area, was obviously quite outstanding.

By far the most profitable type of irrigation equipment for the manufacturer, the merchandiser and the business community generally is spray irrigation equipment. On any comparable basis it requires more capital for bigger power sources in engines and electric motors, more fuel and lubricants and infinitely more specialised equipment than all other methods of applying water to land. Added to these business incentives, spray irrigation is also the most spectacular irrigation procedure. For instance a line of sprays operating on a hot day in surroundings which are parched and dry, is a pleasing and impressive sight. Because a spray system applies water slowly and completes only 1 - 2 hectares (2–4 acres) per day, this irrigation spectacle may be continuous for weeks or months at a time.

Contrast the spectacle of spray irrigating at the rate of one hectare (two acres) per day with the complete lack of spectacle in the Keyline irrigation of 20 hectares (50 acres) per day by the Pattern system. With this latter system there may be little water visible from a short distance away. All that is visible, is a man apparently strolling around and occasionally bending down and straightening up. But he is irrigating 20 hectares (50 acres) of land in one day!

Speaking at the 1963 Australian Academy of Science’s National Symposium on “Water Resources, Use and Management”, Professor Geddes tells the story of the development, at Badgery’s Creek, of farm waters for irrigation purposes to grow feed for a dairy herd … “as primarily an attempt to study the economy of a self-contained irrigation system dependant upon farm run-off.”

The paper dealt with spray irrigation only, mentioning it throughout as “irrigation” and not as “spray irrigation”. The conclusion was that the work … “has shown that an irrigation system based upon farm run-off can operate economically in the town milk supply industry and that it can lower production cost substantially. Up to date the university work has been confined to a town milk economy… the question has often been raised whether the returns would be sufficient to justify the development of a water harvesting scheme for other forms of livestock production. No answer can be given yet, but the work points to a method of predicting the required level of production from other classes of livestock for profitable operation.”

These qualifications were no doubt necessary when discussing the work at Badgery’s Creek and its limited scope.

However, the answer can now be given and at least three of the methods of irrigation discussed in this book will fulfil the requirement of profitability for “other forms of livestock production”. Two of the three methods are original Keyline developments, namely Pattern irrigation for hillsides and undulating lands and Flood Flow for flatter lands. The third method is orthodox contour bay irrigation.

Irrigation from the water resources of our farm and grazing land should be made as profitable as is possible, and as was mentioned in the first part of this book: “Whether irrigation will produce much profit or result in substantial losses often depends on just the right choice of irrigation procedure.”

Our sole purpose in publicising Keyline, through books, field days, lecture tours and schools for university, school and college students and practical farmers, has been to encourage the use of, what we consider to, be worthwhile practises. Our argument is against those who promote any one irrigation system irrespective of its suitability to varying situations.

Professor Geddes describes water harvesting as: “The collection and storage of any farm waters, either run-off or creek flow, for irrigation use”.[23]

XXV. LUXURIANT FORESTS IN DRY COUNTRY.

A. Droughts - natural or precipitated disasters?

Natural landscapes of trees and grass have been turned into desert and given a desert climate by the action and the ignorance of man about the way to work with the soil and the available water. A change of climate caused by the deterioration of the balance of the landscape over large areas, has occurred many times on the continents of the world during the last few thousand years[24].

But with good advice, faith, hard work and dedication this can be set aright comparatively quickly.

This chapter is part of a story, past and current, of one particular grazing property, 'Carisbrooke'. The property, owned by a committed Christian couple, Charlie and Anne Phillott, covers nearly 25,000 ha (100 square miles) in Queensland, Australia.

By 1966 when P. A. Yeomans was called in for advise, this property and its owners had suffered drought for all of the six years since Charlie and Anne purchased the property. Five thousand of the six thousand sheep, which they attempted to hold through the drought, had finally died. The homestead sat on a clay-pan[25] about 260 ha (one square mile) in area.

The property was afflicted by drought and lack of finance. Although the average annual rainfall was reputed to be 355 mm (14 inches), less than half this average had fallen in the six years. Financial credit was restricted and debt compounded.

What could be done using Keyline?

B. Drought resistances procedures.

The first part of the following account is taken almost verbatim from 'The City Forest' by P. A. Yeomans published in October 1971. (Headings have been added.)

'We follow the usual routines;

- Firstly, with the owner, an inspection was made of the entire property within the 65 Km (40 miles) of boundary fence;
- Secondly, we pin-pointed the principal features of the landscape and envisaged the design for all the land; and
- Thirdly, we selected the most advantageous place for a starting-off project within this design.

The last item was critical since the improvement of the property had to be of unusually high significance and it had to cost so very little.

Like most properties that cover several hundreds of square kilometres (many tens of square miles) in these dry regions, this one had ’hard’ impervious areas that shed most of the rain that fell on these areas. The run-off from storms normally disappears in a bed of sand or a dry creek.

The plan was to intercept the rainfall run-off from some of the hard country with a diversion channel and lead the water to a large shallow storage dam for which we selected a site.

C. Design for climate.

Apart from the land shape, we designed for the climate. Firstly, it was known that the drought could continue for years and secondly, there would be some rain every year. It could be as low as 75 mm (three inches) but no previous drought year had been without rain. Therefore the design provided that the drought would be broken before the drought broke and with as little as 75 mm (three inches) of rain.

So far a day and a half had been spent on the examination during which time the grazier had made his decision on the project. Another day and a half completed the more critical levelling and pegging. Yeomans returned a few weeks later for one day to supervise the start of the construction that was completed by the owner and his very helpful neighbours shortly afterwards. What had been completed was a Keyline Flood-flow irrigation project. It was made up of a diversion channel 2 Km (well over a mile) long; a dam 2.4 metres (eight feet) deep[26]. There was 4,600 M^3 (6,000 cubic yards) of earthworks in the wall. The dam would cover with water somewhat less than 40 hectares (100 acres) of land[27]. The dam was equipped with a 625 mm (25 inches) diameter outlet pipe. From the outlet a long contour bank to serve as the irrigation channel was constructed. Steering banks were constructed from this channel, extending down the maximum fall of the very gently sloping land.

D. Irrigation dam filled with 15 mm (60 points) of rain.

During the year following construction, less than 90 mm (three and a half inches) of rain fell. However, within a few weeks the first fall of 15 mm (60 points) nearly filled the dam and irrigation commenced a week later. Twice again in this first year of exceptionally low rainfall - low even for a period of long drought -the dam received water from the ’hard’ area to fill and overflow. Each time the dam filled, the water was used to irrigate, when the soil required it, until none was left. The response of the soil and the fodder growth were nearly immediate and from the pictures received by the author this section of the property was quickly transformed.

That drought continued for five more years to break in April 1971.

The project and the property flourished through the drought.

A second and much grander stage of the landscape design was constructed. The rain that broke the drought also filled, for the first time, a newly completed storage dam several times larger than the first.’

Over twenty years passed…

…Then in September 1990 the property was judged best in the state as the following account testifies.

E. Centenary Land Management & Conservation Award

The following text is from a pamphlet published by the Association.

1. State Award winner ’Carisbrooke’, Winton, Queensland.

In 1990 the United Graziers’ Association of Queensland conducted a Land Management and Conservation Award in conjunction with its Centenary. Six regional winner awards were made in the first round of judging. After further judging, Charlie and Anne Phillott of ’Carisbrooke’ Winton were awarded the state wide winner prize and have been nominated as Queensland’s primary producer entrant in Land Care Australia Limited’s National Landcare Awards.

The award was judged on the criteria of -

- Land use for sustainable production,
- management techniques for land and livestock,
- property planning for management and long term development, and
- wildlife habitat management and retention.

2. ’Carisbrooke’

a) The property.

’Carisbrooke’ originally part of the large Bladensberg Station, the property was excised in 1936, and the Phillotts came to the property in 1960. ’Carisbrooke’ is approximately 20,000 ha (50,000 acres) in size. Approximately 8,000 ha (20,000 acres) is highly productive Mitchell grass downs and gidgee ridges, 4,000 ha (10,000 acres) is tableland or ’jump up’ spinifex country and the remainder is gidgee ridges and water course below the tableland.

Property vegetation and soils vary. Charlie concentrates his grazing enterprise on the better pastures of the open largely treeless Mitchell grass pastures with associated herbage. Buffel grass has been successfully introduced into some watercourses. Ridges feature scattered gidgee while a variety of eucalyptus including coolibah grows along the watercourses. The channel country is now largely buffel grass pasture that colonised the water courses initially and then spread. In common with the downs, gidgee dominates the ridges and the eucalypts including coolibah are found in the waterways.

A variety of vegetation, including spinifex grass in association with mulga, lancewood, a number of wattles, eucalypts and beefwood, is found on the decomposed sandstone tableland.

The tableland areas are left largely undisturbed and therefore act as a drought reserve and wildlife habitat. This aspect is used to advantage in a limited on-farm tourist enterprise that capitalises on the scenery of the area.

The property has an annual average rainfall of 300 mm (12 inches) traditionally falling mostly in summer. Recently the pattern has become variable with greater winter rainfall.

b) Grazing Production

’Carisbrooke’ produces predominantly wool although some cattle are run.

An average of 6,000 sheep are carried on ’Carisbrooke’. They are all merinos of Boonoke blood producing medium quality wool. Ewes are normally joined to lamb in February - March, sheep are shorn in early August and lambs are weaned at shearing.

As a result of the Keyline water control scheme used on the property, available water and plentiful feed assist early lambing. Lambs are then better able to withstand any dry conditions that might occur in August - September.

A Santa Gertrudis breeding herd of 400–500 head was run but due to the drought years 1981–1985 the herd was sold. Since then cattle have been periodically agisted on the property as pasture permits.

While pasture species have been introduced on the property, production relies on the native grass species.

3. Property Development and Planning.

a) History

During the early dry years on the property, Charlie and Anne realised that the only natural asset unable to be fully utilised was runoff water. They noted that there was considerable available water at times of concentrated rainfall.

In 1965, Charlie was given a copy of the second Yeomans Keyline book ’The Challenge of Landscape’ written by P. A. Yeomans (The book is now out of print). So impressed were they with the concept that they sought professional advice of “P.A.” and commenced developing ’Carisbrooke’ according to the Keyline principle.

While modified to suit circumstances and local conditions, the principles have been followed for the last 25 years. Charlie believes that the scheme has fulfilled its aim, which is “to convert water (both run-off and stored water) to native pasture as quickly as possible”. Keyline continues to provide a plan for the future development of ’Carisbrooke’.

The effect of using the Keyline system has been to introduce some stability into the property’s grazing production. Available water and as a consequence more available feed has provided a drought reserve not normally found in that district. Therefore stock can be of higher quality ’finish’, which attract higher prices.

According to Charlie they also “go a lot longer in a drought”.

b) The Keyline principle.

The principles of Keyline are:

- The rapid application of water to irrigation land but recognising salinity, water-logging and associated problems,
- The specific cultivation methods that combine soil aeration with water control, and
- Earthmoving principles that are both economical and effective.

Those principles are employed in accordance with the ’Keyline Scale of Permanence’, which considers 8 factors of property management in their order of relative permanence and effect on property operations.

1. Climate
2. Land shape
3. Water
4. Farm roads
5. Trees

6. Farm buildings
7. Fences
8. Soil.

All these principles and factors were considered by Charlie in his property development.

Both the Yeomans Keyline pattern (hillside) and Keyline Floodflow irrigation system provide overall and balanced property development recognising economics, livestock production and pasture development.

The overriding principle is to make the greatest use of water as it flows from the property. The object is to control the water and convert it into pasture both by increasing water infiltration into the soil and storing it for later re-use at critical times to aid pasture growth. According to Charlie, “we want to encourage adoption of this system because of the long term benefits. However, there are immediate benefits available. If landholders commence the system, there can be an immediate response because it can be implemented in small stages”.

c) Keyline on ’Carisbrooke’.

When Yeomans visited ’Carisbrooke’ the first project was a complete property survey (view and assessment) which was carried out in early 1966. A series of level channels and a dam (Boards dam) were constructed commencing in October 1966. They were located at specific sites identified from the levels taken during the survey. The diversion channels were located and constructed to catch run-off water and divert it to the holding dam. Boards dam was sited off the watercourse and fed by a diversion channel.

One advantage of locating the dam off the watercourse is that the soil there is often more suited to dam construction and irrigation.

Diversion channels are constructed by pushing soil up into a series of level banks. There are a number of benefits to using level channels. One is to ensure that any flood water flows over those banks rather than the dam wall. Because the diversion channel is level, the water being transported to the dam travels slowly and deposits its silt. In addition, water backs up above the diversion bank and floods the ground for a period of time and for a distance of up to 100 m. As a result there is significant water infiltration at those times causing maximum retention of sub-soil moisture. In many of these areas buffel grass has been planted on what were largely unproductive clay pans. A highly productive Mitchell grass and buffel grass pasture now exist. Because the bank wall is kept moist, a significant growth of grass and trees occurs there, too[28].

Below Boards dam a 65 ha (160 acres) irrigation area was established. An irrigation channel from the outlet pipe of the dam distributes water into a series of irrigation bays. As the water fills the irrigation channel Yeomans “Water-gates” are opened and the water flows into each of the bays as required. Water then covers the whole area of each bay ensuring the pasture is adequately watered at times of greatest need.

The irrigation area was successfully watered for the first time in March 1967. From that time, the Keyline Flood-flow system has been continued and adapted to local conditions by trial and error.

In the years of 1971 and 1972 further construction was carried out. A larger dam (Isles dam) and associated channels were built. Since then the capacity of the dam has been increased and the diversion system is being modified and refined. Charlie has plans to commence a further irrigation scheme to use the available water in Isles dam. The short term aim is for approximately 200 ha (500 acres) to be irrigated at critical times to promote pasture growth. Then the system can be continued as required.

One major requirement to maximise production when using the Keyline system is the ability to aerate the soil thereby allowing water infiltration and breaking the soil ’hard pan’. Purchase by Charlie of a Yeomans ’Slipper Imp’[29] plough to replace the traditional chisel plough was a major breakthrough allowing him to use the available water to the greatest effect. The tyne (shank) design of the plough is particularly effective in breaking open the soil but not turning it over. By using a specific Keyline pattern of ploughing the ’Slipper Imp’6 encourages water infiltration. Sub-soil moisture retention encourages pasture root systems to develop with the result that pasture growth is enhanced and has greater ability to withstand the moisture stress of dry periods.

After maximising pasture production, management of the pasture has become important to ensure that grasses are not over-grazed and the desirable species continue to dominate. Regular grazing and then ’spelling’ allows pasture re-growth to take maximum advantage of available water and the soil renovation.

While the soil aeration process is at present largely confined to the irrigation area to maximise its production, there are opportunities for broad scale use to enhance pasture growth.

4. Property Management

Charlie believes that an important aspect of Keyline is that every small stage of development can produce an immediate positive response.

The cost of developing the system on ’Carisbrooke’ has been borne from within the normal day-to-day operating costs of the property. Therefore, the speed of the developments to-date have been dictated largely by seasonal returns and Charlie’s time to operate ‘dozers and other equipment. In Charlie’s opinion time is also required to allow nature to create the correct balance between trees and pasture as a result of the more available water supply.

Keyline has provided a drought strategy for ’Carisbrooke’. Stocking rates are lower than the district average. Accessible water and more available and higher quality feed allow for early weaning of lambs and calves. Lambs are able to be weaned early at 10–12 weeks and put on to better pasture in the irrigation area. Ewes are then able to retain condition for longer in dry times.

Various pasture species have been trialed in the irrigation area on ’Carisbrooke’. They include dolichos lab lab, Nunbank and Boorara buffel, Hunter River lucerne and most have not become permanent components of the pasture. The present pasture mix in the irrigation area is lucerne, buffel grass and Mitchell grass.

While there are plans to extend the Keyline system (and it is able to be continued indefinitely to take in a greater proportion of the property), the rest of the property is managed largely according to standard practice. The irrigation area and dams provide higher quality feed allowing more flexible management of the remainder of ’Carisbrooke’.

The original property survey allowed fencing to be sited on the crests of ridges where possible and so follow natural features and ’lines of water control’ which are determined by the placement of the dams and diversion channels. Paddocks are 1,800 - 2,300 ha (4-5,000 acres) in size.

Although weeds were a problem in the early years on the property, they have been largely eliminated. Constant control by poisoning and chipping is required, particularly of prickly acacia.

5. Wildlife habitat management and retention.

A considerable diversity of plant and animal species remain on ’Carisbrooke’. This is due to the minimal use of the tableland for grazing and the retention of natural vegetation along ridges and water courses. No specific management is undertaken other than to allow nature to take its course. Over 70 bird species and over 30 native plants have been identified on ’Carisbrooke’.

6. Conservation Award Summery

In the opinion of the judges, the property of Charlie and Anne Phillott demonstrated the best practical combination of all the criteria considered in the UGA Centenary Land Management and Conservation Competition.

Use of an innovative system such as ’Keyline’ capitalised on available water and soils, topography and pasture while encouraging the natural balance of wildlife. Conservative stocking rates, a balanced livestock management program and long term plans to continue the Keyline system to improve productivity without degrading soils and pastures were considered to be outstanding.

KEYLINE DESIGNS - CONSULTING SERVICES

Biography - KEN B. YEOMANS H.D.A.,

Born in Sydney, as the youngest son of P. A. Yeomans, Ken graduated from Hawkesbury Agricultural College, Richmond N.S.W. in 1969 with a Hawkesbury Diploma of Agriculture (H.D.A.). Ken Yeomans was a foundation member of the Agricultural Technologists of Australasia and is a member of the Irrigation Association of Australia and the Biological Farmers of Australia. Ken has a consulting practice in property design and development. This work includes the site selection, survey and plan preparation of earthworks for large farm dams and Keyline gravity irrigation systems as well as assessing and making recommendations on; rebuilding the living fertility of soil, grazing management, cultivation practices, cropping programs and subdivision design. Throughout the states of Australia and overseas, for clients with land holdings ranging in size from under four hectares to over four hundred thousand hectares, Ken Yeomans has applied his knowledge and experience of Keyline on family farms, multiple occupancy communities and rural stations held by large corporations.

Ken is a born again, Spirit filled, believer in Yeshua HaMashiach (Jesus the Messiah) and with his wife, Robyn are Messianic Ministers who founded Beit Gan-Eden Messianic Community in Surfers Paradise Queensland in 1999. www.bgemc.org

Plate 56 Kenneth Bruce Yeomans

A. Keyline design services

The design process often reveals unsuspected potential and dispels illusions. It is a satisfying experience.

The process employed to discover the hidden potential of the land you have in mind is based on the discoveries and insights of the late, “P.A.” Yeomans. This is combined with the experience gained implementing Keyline on our own land, and consulting on countless other properties both here in Australia and occasionally overseas.

One of the important tasks of your Keyline consultant will be to provide you with factual information on your property’s potential so that you will avoid mistakes and be able to proceed with confidence.

Every property is unique and has its own special features and best potential.

There are two aspects to the process of Keyline development - the planning and the doing; or to put another way; the design and the implementation.

1. Design.

The Keyline Scale of Permanence provides a priority guide to the various factors considered in the design of the landscape. In this scale the utilisation of the water resources of the landscape is designed after considering the climate and topography (land shape). Then the location of roads, trees, buildings and fences may be logically planned in this order.

Design is done in two integrated stages: in the office and in the field.

A) In the office.

The initial office work speeds the assessment. It is best done using the information derived from detailed contour maps of the area. Based on this initial assessment key points within the apparent design potential of the property are selected. The vertical relationship of the features of the landscape can then be established. Preliminary plans and designs can be formulated. The practical design work starts from the key points and revealed relationships.

B) In the Field - On Site.

During the initial on site survey of the property, contour or grade lines will be pegged as required from the key points previously selected. Dam sites may be chosen, pegged, volume estimates made and the best irrigation area delineated. This work is actually done on site. The first stage or starting project of the plan is laid out on the land. This is Keyline planning in action. Detailed design of Floodflow steering banks is not usually done during the first few days.

(1) Pegs

A bundle of fifty pegs, survey marker stakes, should be available on the first day although two or three hundred pegs are commonly used during the first three days of the design process. The length of the pegs recommended is 1250 mm (4 feet). The preferred pegs are 1200 mm by 10 mm fibreglass rods, commonly used for electric fencing. These sell for about $3.00 each. Alternatively 25 mm square (inch by inch) timber pegs are occasionally used. These should be pointed on one end and painted white for about 20 cm (8 inches) on the other end. 1200 mm wooden pegs are better than 900mm wooden pegs, which are not recommended as shorter pegs may disappear from view when grass is long.

Short temporary markers may consist of about 500 mm lengths of heavy plain wire with a loop twisted onto one end onto which bright flagging tape is attached.

Up to 20 star steel posts may be used as permanent sighting pegs. However star steel posts are too heavy and cumbersome for general survey use.

(2) Helpers

It is naturally preferable for the owner or manager to accompany the consultant during the survey. As well as this, two additional helpers may be required, one to carry and hammer the pegs and the other to hold the end of the measuring cord. These helpers will be needed at different stages of the design. Interested neighbours and/or family members are suitable for this task.

After you proceed with a Keyline assessment of your land, you will be in a better position to successfully develop the full potential of your property.

2. Implementation.

The specific details of project construction, sources of equipment, cultivation guide lines and appropriate management techniques to increase the biological fertility of the soil, can best be explained on site. Keyline Designs can assist you with the local interpretation of the principles.

B. Getting the benefits.

1. Get a detailed topographic map of your area.

Keyline design pays particular attention to the vertical relationships of important features within the landscape. An important aid to the design is an accurate topographical (contour) map.

Scaled topographical maps show features like creeks, roads, contour lines, spot heights, buildings, dams, etc. Such a map will save hours, possibly days of surveying during the assessment process. Maps at a scale of 1 in 10,000 are the most detailed that are generally available, although 1 in 100,000 or 1 in 250,000 are usually better than nothing. The maps should disclose the size of any catchment areas that feed into the property, unless this area is too vast.

The various state Departments of Mapping and Survey can be very helpful. In Queensland, if the topographic map doesn't show the property boundary then request a cadastral map of the property, preferably at the same scale. This may be arranged over the phone. The maps can be aligned using a light table or window and the property boundaries traced onto the topographic map. This way you can add the property boundaries to the topographic map yourself. When you are satisfied with the accuracy of the boundaries it is a good move to have the map laminated. It may be beneficial to hinge six transparent overlays to the map. This allows one transparency for each factor in Keyline scale. Planning can be sequentially developed on each sheet. Erasable ink enables corrections. Each factor is planned on its own layer it leaves the more permanent layers below undisturbed. Aerial photographs are sometimes useful. Orthophoto maps are contoured aerial photographs, these are excellent. If you are unable to obtain a suitable map locally, Keyline Designs may be able to do so, although detailed information on the location of your property is essential.

It is preferable not to draw inside the property boundaries on any map you are intending to send in to Keyline Designs for appraisal. If notation is required within the property boundaries, send two copies, one clean.

2. Consider timing for on site planning.

Climate and seasonal work loads may be a factor for consideration. Others in your area will be interested in Yeomans Keyline Designs. Sometimes hosting a district meeting for a Keyline address results in the sharing of travelling expenses.

3. Contact Yeomans Keyline Designs.

Current consulting fees and expenses may be found on the Keyline web sites. Internet: http://www.keyline.com.au and
http://www.keyline.org
Email: info@keyline.com.au
Phone International 61 7 5591 6281 Office hours Brisbane time Within

Australia (07) 5591 6281; Fax (07) 5527 0847 or
Cell phone 0418 745 120.
Postal address: Keyline Designs
P.O. Box 3289, Australia Fair Southport, Queensland, 4215
Australia.

Then and now…

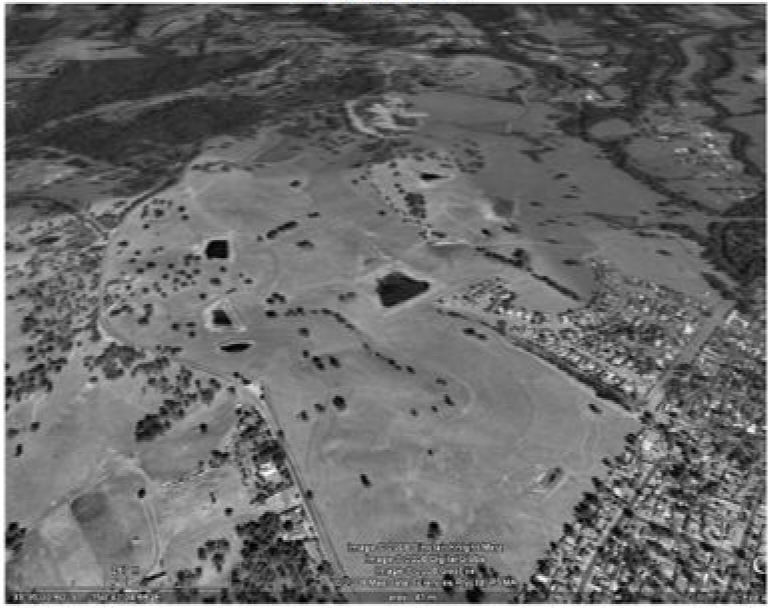
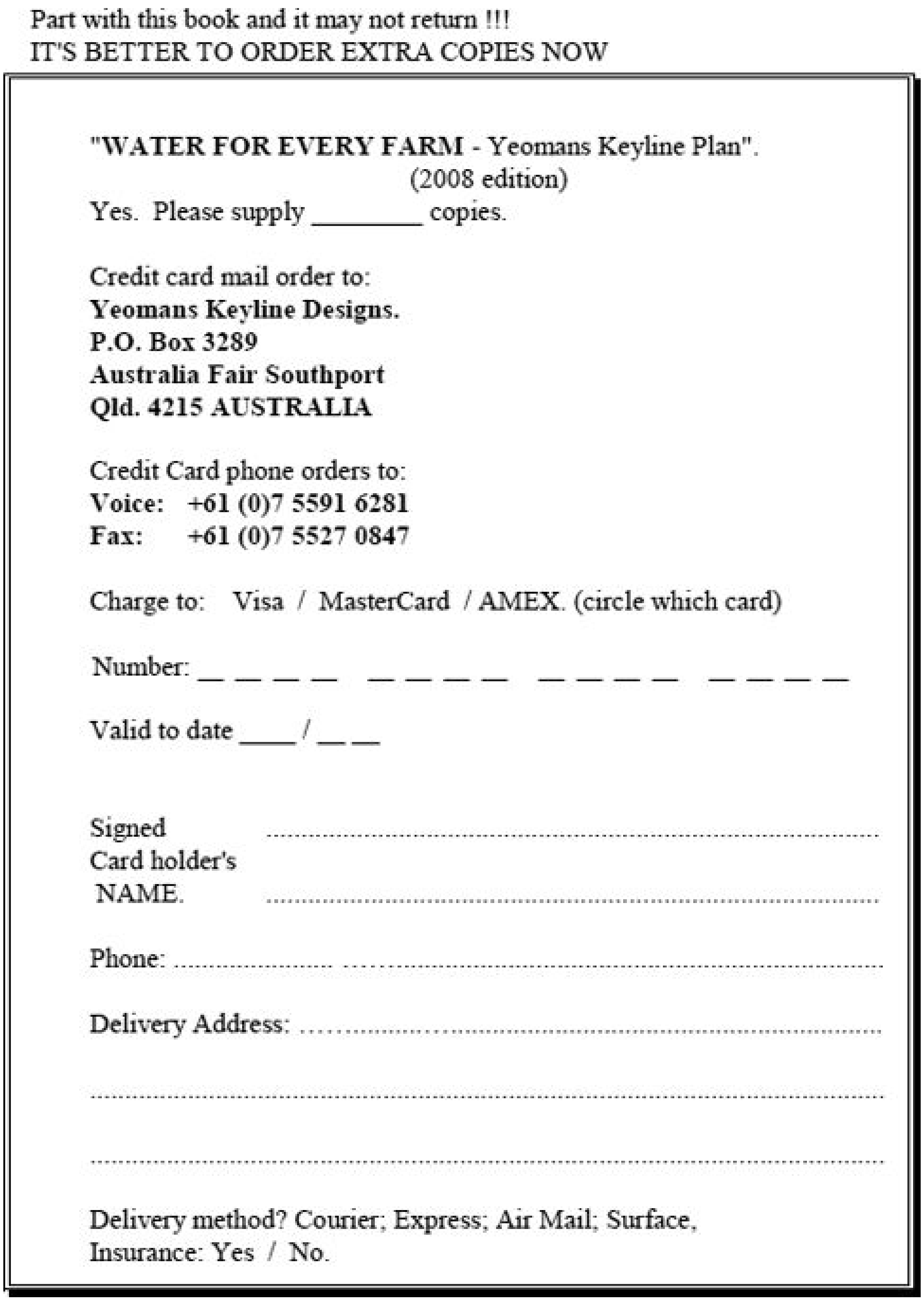


Plate 57. A tilted to match Google Earth image of Yobarnie in 2008. Lat/Long: 33°35'01.38"S 150°41'54.45"E. Some water conservation channels and a dam are removed for urban subdivision within which stormwater, no longer valued and stored, is quickly drained away. Residents have potable town water inadequate for gardens, yet the increasing runoff from subdivision could provide plenty of yard water.



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www.keyline.com.au/form03.htm for online ordering.

2) Paperback in monochrome, A5 size.
www.keyline.com.au/form01.htm for online ordering

[1] The “lockpipe system” is basically a large diameter pipeline, equipped with, inflow cone strainer, valve and most importantly baffle plates which prevent water leaking along the outside of the pipe. It is positioned through the bottom of the wall of each dam and permits the rapid release of the water for either irrigating or for the transfer of water around the property.

[2] Over production or under consumption? It is probably obvious that if money is not a limiting factor, most consumers would purchase more and select for quality and favour local products. Each of us is either a producer or consumer and which almost depends on the time of day. Producers want customers (consumers) who have money to spend. Consumers we generally know what we want but lack the money to become customers. So do we really have “over production”? I think we actually have “underconsumption” due to shortage of disposable income. New funding methods are need that will enable an increase in local consumption. The Robin Hood approach of robbing the wealthy to dole to the poor is morally indefensible and actually has minimal effect on total consumption. Also encouraging savings and investment doesn’t address the issue as savings always further reduce consumption and the investment of savings increase production further.

We need to develop policies that will both, firstly; increase the purchasing power of consumers without increasing their indebtedness and secondly; reduce the domestic selling price of our own industrial production without penalising producers and distributors. Increasing wages will never achieve these goals as wages are a cost of production, which must be included in the selling price. So selling prices must rise to pay for the extra wages. A vicious cycle.

Possible policy options that will work include: consumer rebates and consumer subsidies on local products directly related to production efficiency. See http://www.ecn.net.au/~socred/index.html for more information.

The spin offs from all these policies would be increased local consumption and expanded local employment. These proposals may be funded by a Commonwealth or a State bank. Government banks have the constitutional authority to issue credit that is both debt and interest free. It is important to realise that interest and debt free local currency is what tourists, exporters and foreign investment cause to be created locally. Money issued to tourists, exporters and foreign investors are the best examples of money that is issued locally that is free of both local debt and local interest charges. As such these funds can actually reduce total local debt. Virtually all other money (bank deposits) is loaned into existence at interest and so can never reduce total debt. See www.moneyasdebt.com and have a look at the video “Money as Debt” on http://www.brasschecktv.com/page/135.html The most creative proposal to painlessly dissolve the monopoly of credit I have seen is within in the book the “Democratising Banking” By Charles Pinwill. ISBN 0 646 22696 7 Published by Freedom’s Booksearch, PO Box 7372 Toowoomba Qld 4352.

Ken Yeomans, Editor.

[3]The latest figures supplied to the author in February 2000 show the previous ten year average to be 318 farms (peaking in 1995–4 at 519) irrigating a yearly average of 23,980 ha. The ‘98/99 figures are 430 farms and 43,127 ha, which is an average of 100 ha per farm.

If we divide the total funds invested in the project (including the dam) by the number of farms served with irrigation water we discover for ‘97/98: $386,676,000 divided amongst 440 farmers is $878,809 per farm. (See table on next page, which includes latest figures)

[4] W.R.C. 1991/92 Annual Report Appendices Table WM 5, Water Charges pp. 66.

[5] A preferable course of action, which has present relevance, would have been for the State or Federal Government Bank to be instructed to issue financial credit, free of both debt and interest. Then progressively distribute this new money through out the economy, as a share dividend, paid equally to all citizens. The increased purchasing power would initiate a consumer led recovery. The

new credit would first appear in the commercial banking system in the same way that payments for exports do, namely, as new deposits. Genuine debt reduction becomes possible. The private banks usually use deposits as a justification to issue new bank credit. It may be necessary to someway limit this re-issuing process to prevent inflation which debt based bank created deposits cause. - Editor.

[6] This account was originally written by P.A. Yeomans in the first person. The third person is used here for ease of comprehension. Editor.

[7] Renaming Soil Conservation practices into “Landcare” is missing the point and futile if the defensive design goals of soil protection and water disposal are not corrected. Editor.

[8] Originally 20 feet. The extra size matches better to pipe lengths and improves the storage ratio (water for earth) by better than 6%. Editor.

[9] In a 1985 publication, “Design and Construction of Small Earth dams” by K. D. Nelson, the settlement allowance recommended is 5% for all wall heights between 3 and 10 metres. The extra 3% over the Keyline recommendation can add over 5% to the volume of the earthworks required. Editor.

[10] PVC and reinforced large diameter polythene pipe are also available.

[11] The use of U section rubber between the baffle plates and the pipe has been replaced by the use of silicon gel and other sealing products - Editor.

[12] Preferably: The Yeomans Keyline Plow or similar earth loosening equipment. - Editor.

[13] “Back blade” is a term describing the use of the bulldozer blade to smooth the surface whilst driving in reverse. - Editor.

[14] What a pity it will be for the long term best development of any property if it has a water disposal (soil conservation) design locked into place with trees planted along the contour banks. Editor.

[15] A purchase inquiry to the Department of Primary Industries in Queensland in 1992 resulted in a price range of $1 - $2 for less than 50 trees dropping to from 50¢ to $1.00 for more than 1,000 trees. Editor.

[16] The Bunyip is no longer in production but the description may be of value to those building their own. Editor.

[17] Distance of the staff from the levelling instrument can be determined using the stadia lines. These are the two smaller cross hairs, one above the centre line and the other the same distance below the central cross hair. These two short cross hair, stadia lines, are spaced so that the length of staff seen between them is 1% of the distance to the staff from the survey instrument (automatic level). For example, if subtracting the lower stadia reading on the staff from the top stadia reading results in 45 cm between the stadia lines then the staff is 45 metres from the instrument. Editor.

[18] P. A. Yeomans Pty Ltd., received the Prince Phillip Design Award in 1974 for the Bunyip Slipper Imp with Shakaerator. - Editor.

[19] “Rational grazing” was a term used (probably coined) by the late Andre Voisin who developed a grazing rotation that altered the number of paddocks (fields) in the rotation, and the time in each paddock (field) so as to bring the stock back to the number one paddock at exactly the chosen stage of pasture growth. Removal of stock before regrowth occurred was a feature of this system. Rational grazing aimed at producing the best feed quality for the stock. The rotation timing coincided with that which developed within Keyline. Although Keyline development was aimed at rapidly building biological soil fertility. Voisin documented a great improvement from one chisel renovation (cultivation) however he also documented the soil reverting to original type over a 7 year cycle following the once only chiselling. The first few years produced increased yield but the subsequent

years were below the control plots. Voisin apparently never learned of the compounding benefit from the three annual chisel cultivations developed in Keyline. Editor

[20] P.A. Yeomans is the one writing in the first person throughout this chapter.

[21] P.A. Yeomans is the one writing in the first person throughout this chapter.

[22] These limits have been passed by using larger pipes and larger channels. - Editor.

[23] Clearly water harvesting is and always has been a part of Keyline design. Editor.

[24] The following Biblical references shed light on lack of rain this: Lev 26:3-4; Deut:11:13-14, 16–17; Deut 28:12; 2 Chr 7:13-14; Jer 3:3; 5:24-25; Jer 3:7;14:7; Hosea 10:12; Zech 10:1; Matt 5:44-45; Acts 14:16-17; Heb 6:7.

[25] A clay-pan aptly describes these areas of flat land from which the top soil has been blown away and nothing much grows on it.

[26] This depth being the height of water above the lockpipe system and not the depth of the water down from the top water storage level to the base of the excavation.

[27] The volume of the dam could be roughly estimated at 320 Megalitres (270 acre feet). The surface area times one third of the depth using appropriate units, which is the formula for a cone.

[28] The first diversion channel was constructed across a tree-less plain. The effect of the channel, with each rainfall run-off event, was the regular inundation of a wide strip of land beside it. This automatically sowed and regularly watered what developed into a contour strip forest all along the channel wherever the water covered.

[29] ’Slipper Imp’ is the original name for the Yeomans Plow Company’s narrow tyned ripper called the Keyline Plow. Editor