LAND RESOURCES AND LAND RESEARCH

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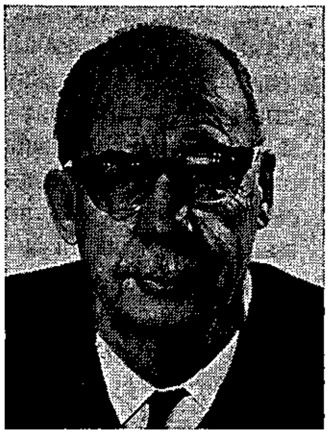

C. S. CHRISTIAN

The name of William Farrer lives in agricultural science not only because of his contribution to the Australian wheat industry, but as much because he so effectively demonstrated and proclaimed the role that science should play in the development of Australian agriculture. His was one of the earliest and most convincing examples of the contribution that the scientific approach could make to agriculture and he did much to spur the development of agricultural research in this country. His impact on science in Australia was wider than his own achievements; for instance, his work was quoted as an example

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Mr. C. S. Christian has been a Member of the Executive Committee of CSIRO since 1960. He received his initial training at the University of Queensland in Agricultural Science (B.Sc.Agr. 1929) and at the University of Minnesota (M.S. 1932) and the Agricultural Research Station at Rothamsted in England.

His early work with CSIRO, which he joined in 1930, was in the field of wheat genetics and wheat breeding. Subsequently, he conducted a programme of pasture research in Queensland for many years. In 1946 he was appointed leader of the North Australian Regional Survey, a unit established by CSIRO at the request of Commonwealth and State Governments to make scientific surveys of Northern Australia in order that the information necessary for the formulation of land development policies might be obtained. This unit later became the Division of Land Research in CSIRO and has been responsible for comprehensive natural resource surveys of nearly a million square miles of country on the Australian mainland and in the Territories of Papua and New Guinea.

Mr. Christian was responsible for the development of what is now widely referred to as the integrated approach to resource survey and assessment. This approach has been adopted by FAO and UNESCO and the Department of Technical Co-operation in the United Kingdom. It has been practised in many countries and Mr. Christian was appointed Chairman of the UNESCO international Advisory Committee for Natural Resources Research in 1967.

In conjunction with his work of resource assessment, Mr. Christian was responsible for establishing and administering the Katherine Research Station in the Northern Territory and, in conjunction with the Western Australian Department of Agriculture, the Kimberley Research Station on the Ord River.

Mr. Christian currently represents CSIRO on the Standing Committee of the Australian Agricultural Council, the Standing Committee of the Australian Water Resources Council, and the Standing Committee of the Australian Fisheries Council. He is a member of the Australian Meat Research Committee.

Mr. Christian has represented Australia at many international conferences especially those concerning the use and development of natural resources. In 1962 he was elected a Fellow of the World Academy of Art and Science.

Mr. Christian has been a Chairman of the Australian Institute of Agricultural Science and in 1960 was elected a Fellow of the Institute. He is also a recipient of the Institute's Medal.

of the wonderful economic benefits that scientific research could bring to this country in the debates in Parliament which led to the formation of C.S.I.R.

The story of his wheat investigations has been well covered by other orations. Tonight I intend to start with another part of Farrer's life and lead from this to talk about the subject of land resources and the development of modern approaches to land research and land assessment.

Before he settled at Lambrigg in 1886, Farrer was a contract surveyor with the Lands Department for 11 years; an experience which must have contributed much to his well developed ecological appreciation of agricultural land environments. This played a prominent part in his subsequent regional wheat trials. By the time Farrer left the Lands Department, the general pattern of land development in Australia had been established. This period more or less marks the end of one era, the era during which knowledge of Australia's lands were slowly accumulated by exploration, trial and error and the long, slow process of gaining local experience; and the beginning of another era, one of more precise and scientific study of land and agricultural and forestry production.

In any newly developing country, such as Australia became on the arrival of the First Fleet, land and its natural resources play a dominating role in guiding development. It was not surprising, therefore, that one of the first instructions given to Governor Phillip in 1788 was to proceed with the cultivation of land as soon as possible; and this he did. It was equally not surprising that one of the first lessons Governor Phillip learnt was that Joseph Banks' assessment that "From the fertility of the soil, they might be able to maintain themselves after the first year with little or no aid from the mother country"(1) was either the result of overoptimism, or an indication of a complete lack of appreciation of the limiting characteristics of the new environment.

There followed the search for more productive land. Good land was scarce and even the best land declined in productivity. Clearing land of trees was arduous and density did not always indicate quality. The better arable land near the rivers could be subject to erratic and sometimes disastrous flooding. The climate was harsher than Britain's and droughts were a recurring feature. The imported crops and varieties were not all well adapted. Much of the land was more suitable for pastoral purposes than for agricultural, but pastoral country also deteriorated after grazing. Water for stock was commonly a limiting factor. Distances were great and the transport of animals was easier than that of grain. These were some of the lessons learnt by bitter experience.

Having little agricultural knowledge or experience, the early colonists judged land by its more obvious, tangible characteristics and by subjective assessments translated from their home country memories. They had no tested criteria and it is no wonder that explorers did not always agree. Perry quotes Commissioner Bigge, referring to Throsby's report of the country on his new route from Sutton to Bathurst, "Neither Mr. Oxley nor myself found reason to concur in the description of the country this gentleman, Throsby, transmitted to Governor Macquarie"(2).

After the introduction of the right to purchase land in 1830, there was a rapid and uncontrolled spread of settlement which proceeded through the era of the squatters and after the early gold digging days. From this a great deal of local knowledge of the land was accumulated, much of it gained at the expense of those who failed.

With the introduction of legislation aimed at more control of land and of land tenure, in the latter half of the 19th century, and the trend towards closer settlement, there was increasing need to assess the quality of land(3). However, up to Farrer's day, at least, there seems to have been little organized classification of land as such, appraisals being made on the basis of general descriptions of holdings, with the surveyors being occupied mainly in the establishment of boundaries. There is little evidence of any instructions to surveyors about methods of making land assessment. Much seems to have been left to the surveyor's own experience, and his application of local knowledge. One of Farrer's survey field books from the Cobar area carries meagre notes alongside his traverses, such as: box and pine forest with patches of scrub, open box forest with emu bush, sandy soil, hard ridge, and so on. A surveyor' training was mostly in-service training.

As land surveys became more and more a prior requirement for the application of land administration reforms, land surveyors became very skilled at describing land in terms of its vegetation, surface soil, terrain and water supplies and many of their maps, produced in the first half of the 20th century under arduous conditions and with simple instruments, compare well with modern land assessment maps. The concepts of carrying capacity and of minimum living areas were incorporated in Land Acts and required judgments of productivity. Relatively simple forms of land classification were used. For example, in Western Australia, some millions of acres of land in the wheat belt were classified shortly before and after World War I into first, second and third class lands, mainly according to the vegetation and into sub-classes according to soil. Other States adopted broad classifications such as agricultural lands, and first, second or third class pastoral land. There were subdivisions and amalgamations of lands where mistakes had been made, but in the main, the land surveyors, with little or no training other than in-service experience, did a remarkably good job.

The emergence of specialist studies

It was about the time of Farrer that the sciences related to land use began their slow development and a new concept, agricultural experimentation, began to identify and study the individual components of the agricultural environment. The era of specialist studies of soils, vegetation, climate, and plant sciences was beginning and this continued virtually until the Second World War.

Throughout this period, speculation and arguments raged about Australia's land potential. There were the boosters and the cautious. Many speculations of potential population were made based on its natural resources. Grand schemes for the development of the inland were proposed but did not survive closer examination. There were arguments between those who wished to develop land for agriculture and those who wanted to preserve it in forests.

Climate can perhaps be regarded as the primary factor determining agricultural production possibilities. As climate is reasonably similar over large areas of country, it can be regarded as a regional characteristic. A great deal of work was done earlier in this century to develop simple indices of climate which would distinguish climatic zones with different agricultural potentials or zones of adaptation for specific species. The concepts of effective rainfall and length of growing season were developed, but the annual or monthly data used in the earlier approaches were too crude for anything but very broad generalizations. Gradually attention focussed on the microclimate, in the sense of time intervals, as well as space, and on the response of the plant itself, and agroclimatological studies came closer and closer to practical needs.

Botanists had been active in the colonies from an early date and much had been learnt about plant species. In the absence of climatic data, a practical form of ecological judgment had emerged, vegetation being used as the main guide to climate. Ecological science, as such, developed in the early decades of the 20th century. Ecologists regarded the vegetation as an integrator and expression of the total environment, and therefore, an indicator of land potential. They set up vegetation classification systems based on community structure, and floristics. Indicators of specific environmental features were sought, individual species or associations of species. The broad relationships between soils, vegetation and climate were studied. However, native vegetation does not always utilize the environment in the same way or as completely as introduced crop or pasture species tend to, nor do they always respond to modified environments in the same manner as economic species. Thus, although the extensive vegetation surveys conducted by Cambage, Blake, Costin, Beadle, Wood, Gardner, and others[4] added considerably to the knowledge of the country and the environment, the vegetation approach alone proved insufficient to answer questions about land potential for development or land use purposes.

During this same period, the specialized study of soil developed. Chemical and mechanical techniques of analysis became available. The recognition of soils in the field and the production of generalized soil maps developed slowly. The need for more systematic studies of Australian soils became evident. Prescott and Taylor commenced the systematic field study and survey of soils in 1927 when the Division of Soils was formed in C.S.I.R. They were closely followed by Teakle in Western Australia and by others in other States[5]. At first, soil surveys were mainly restricted to irrigation areas. Soil classification, following the U.S.A. lead, was based on the nature of the soil profile and its various horizons and on the parent material on which the soils were formed. The agricultural usefulness of soils was interpreted from these observations and from local agricultural practice. Soil surveys were extended to many parts of the country and soil surveys began to recognize the need to map soils as associations and soil combinations, rather than soil types and soil series. As soil science developed, more attention was given to soil morphology and soil genesis, soil classification and soil mapping, and to the chemical and physical characteristics of soils. The soil itself, as a separate entity, tended to dominate soil science, rather than the factors of the soil environment responsible for variation in plant behaviour.

At the same time, plant scientists tended equally to concentrate on plant introduction and plant breeding, genetics, and physiology, with emphasis on such things as plant responses to climate and nutrients and to agronomic practices. Each of the specialist sciences was busy finding its own feet and establishing its own criteria, techniques, and classification systems. There was little time for specialists to deal with the other components of the agricultural system. Nevertheless, the progress made in each of these specialist sciences related to land provided the essential basis for Post-War advances, and during their development, there were some notable practical achievements in agriculture. The development of highly productive mixed grass-legume pastures and their nutrition by fertilizer application made outstanding advances leading to new trends in land use and animal production. New crop varieties, the wider use of fertilizers, and larger scale machinery all helped to extend the areas of cultivation. Not all land-use practices, however, were satisfactory and one consequence was the appearance of soil conservation concepts, and special authorities or services, for example, The Soil Conservation Service of New South Wales was established in 1938.

Post-War interest in land resources

The earlier interests in natural resources were rejuvenated during World War II as part of the process of mobilization and afterwards by the desire to regenerate processes of national development. In part, as a consequence of war, there was a good deal of concern for regional planning and decentralization. The war also gave publicity to some of the little developed parts of the continent.

A great deal of unpublished material and new research information on land and land use was brought to light in the many State and regional publications and maps which followed. Associated with these, were more detailed climatic reports such as the regional climatic surveys prepared by the Commonwealth Bureau of Meteorology. The Commonwealth established the Department of Post War Reconstruction and later of National Development. The National Mapping Office and the Australian Atlas of Resources came into being.

The interest in the underdeveloped regions was concentrated very largely in the north of the continent which had been more war-susceptible. Public concern about these empty spaces led to the establishment of the Northern Australia Development Committee, formed by the Commonwealth and the northern States. This called on CSIRO to make scientific surveys of Northern Australia so that development policies might be formulated. As a result, there was established the Northern Australia Regional Survey by CSIRO. The survey of northern regions began in the same year. This unit later became the Division of Land Research in CSIRO.

Landscape analysis

Its task was to assess large tracts of little known country. Most of it presented new agricultural environments where previous attempts at development made little progress or had failed. Although the surveys were of a reconnaissance nature, they were expected to present a permanent and factual basis from which further investigation and planning could proceed.

The methods developed for this purpose will be discussed in some detail as the task called for new approaches to land resource surveys of large areas and the methods which were adopted have been shown by experience to have value for much wider application.

The agricultural and pastoral environment was seen as a combination of many interacting and variable components, not adequately represented by any one component, such as soil or vegetation, alone. Out of this grew the concept of an integrated study of land, the term "land" being used to refer to the complex of all the factors at a site likely to influence land use [6,7,8].

At any spot on the earth's surface, land, using the term in this sense, is the end product of a long period of land-surface evolution in which the parent geological material, successive geomorphic processes, past and present climates, and the changing plant and animal communities of the system have all played interacting parts. The hypothesis adopted was that areas of land which have a common history of evolution and are similar in their present observable attributes should offer similar opportunities and problems for land use, whereas areas with a different genesis should be suspected of being different in their potentials or problems, even if they have apparently similar attributes. Geological, geomorphic, pedological and biological deductions all contributed evidence of the genesis of the landscape; thus this approach required the concurrent examination of land by a group of specialists working together as an integrated team. This was a break away from some of the overspecialized practices of the pre-war period. The atmosphere of the time is indicated by the fact that one high scientific authority claimed that this sort of combined effort by different kinds of scientists would prove impossible. In actual practice, it was shown to be not only possible but extremely rewarding to each member of the group.

It was found that within an area having a common geological and geomorphological origin, a distinctive landscape pattern is evolved. Each of these patterns is composed of a relatively small number of distinctive land elements which recur in an orderly manner to constitute the pattern. Because the landscape patterns consisted of closely related land elements, they were termed "land systems" and the elements within them "land units". Each of these land units represents a particular kind of habitat or narrow range of habitats for plants, animals, or man.

The land system, or integrated land survey approach, as it is often referred to, is not a classification of land types, nor is it in itself a method of assessing production possibilities. It is an analysis of landscape into its distinctive parts, with the identification of similar and dissimilar land types according to their inherent features and not according to any interpretation of these in terms of land use. It aims to present the inherited environmental framework of the landscape in a map form which can be used as a permanent reference for a wide array of studies or interpretations. Interpretations, on the other hand, may be ephemeral, depending upon the current level of technology at the time. As new technology appears, new interpretations may be necessary. The land system framework provides a common basis for sampling for all purposes involving differences in the physical or ecological aspects of land. With respect to land evaluation, it provides a basis for the primary interpretation of possible uses or value and it facilitates the selection of areas deserving more precise study for particular purposes. For each evaluation objective, different sets of parameters may need to be recorded in the selected areas. For example, the sets of parameters chosen to assess suitability of a given land type for road building or for transport of vehicles across a natural surface, would differ from the sets of parameters required to predict suitability for dryland agriculture, or those aimed at mineral detection, or those related to studying disease or pest epidemiology.

Land surveys of the kind described have now covered between three quarters and one million square miles in the north and centre of the continent and in the Territory of Papua and New Guinea. As a result, there is now available a reasonably accurate knowledge of the land types of these areas and to that extent a good deal of the cause of previous speculation about these regions has been removed. The production potentials of different areas and the technologies to be applied to achieve it are emerging from the research programmes subsequently established in a number of selected type locations, but decisions on whether particular areas or types of land should be developed in a specific way must depend upon economic, social, and political factors, as well as on the technological possibilities.

A number of variants of this notion of landscape analysis have emerged at various times. In Australia a parallel approach has been adopted by the Soil Conservation Authority of Victoria[9]. The Soil Conservation Service of New South Wales has adopted the concept in their surveys of western lands[10], and so did Coaldrake in Queensland[11]. F.A.O. and Unesco have applied the concept to a number of other countries. A direct adaptation has been developed for engineering purposes by the Soil Mechanics Division of CSIRO[12].

Because of this wide acceptance of the basic principle, landscape analysis techniques would seem to provide a logical starting point for any wide-scale scheme for land resource inventory and assessment. The need for such a scheme will be discussed later.

Two modern advances are likely to make important contributions to the further development of land resource studies. The first is the use of electronic computers and the second the new remote sensing devices operated from aircraft or satellites.

Computers and mathematical approaches

The modern computer makes it possible to handle greater quantities of data and much more complex calculations than ever before. By adopting suitable mathematical approaches, research workers can now examine simultaneously the significance of a multitude of factors and their interactions in any field of study where measurement is possible. Thus, we find mathematical models being constructed to extend studies in plant growth, soils, ecology, land evaluation, land management, and other fields related to agriculture, forestry, and land and water resources. Systems analysis, a tool long used by research workers, can now be developed in a much more comprehensive and sophisticated manner.

This new facility for handling data could have an impact on land resource studies in two ways. The first is to aid the identification and differentiation of land types by numerical analysis of quantified land parameters, and the second is the prediction of land use potentials and the consequences of land management practices. The mathematical expression of landscape characteristics could conceivably assist in detecting boundaries between land systems or land units in the landscape analysis approach, but in practice, the value of quantitative expression is likely to be greater in the actual description and interpretation of the land types delineated, rather than in their initial recognition. Some current developments tend to combine and perhaps confuse identification and interpretation. The so-called "Parametric Approach", introduced first by foresters, was adapted for military purposes to predict characteristics of terrain of military significance in areas not immediately accessible. Aerial photographs were the major sources of information. Attempts were made to express parameters of the terrain in quantitative terms and then to make a mathematical assessment of terrain in relation to a particular objective. The parameters selected were those of assumed or proved importance to vehicle mobility and other kinds of military activity. This type of parametric approach can be applied to predictions concerning land use, but they involve some pre-judgments of the parameters assumed to be significant for a particular purpose. Therefore, they have more application where some knowledge of land use is already available or can validly be extrapolated from other areas.

Another form which the quantitative approach can take is the development of mathematical models simulating the actual dynamic processes of the land-use complex. The choice of the parameters used in the model is dependent upon knowledge of processes important in the system. The sophistication and extrapolative power of models will increase as research provides more understanding of these processes. While their progress will be limited by the state of precise knowledge of these processes at any time, the models themselves will help to contribute to this knowledge.

The cost of extensive data collection and analysis using mathematical techniques is likely to be justified only in areas of high priority first defined by the landscape approach, or in selected areas where higher levels of understanding, production achievement or management are important.

A good example of the combined use of methods is given by the representative basin project of the Australian Water Resources Council[13]. This project seeks an understanding of the relationships of precipitation to surface and groundwater resources over a wide array of hydrological situations sampling the range of Australian environments. Representative drainage basins were selected according to the general principles of landscape analysis, but the understanding of the phenomena in the basins is being sought by the development of simulation models using large quantities of detailed data.

Remote sensing

The second advance referred to has been stimulated very much by the United States Space Research Programme. In recording images of land surface characteristics, the panchromatic film most commonly used in aerial photography uses only part of the electro-magnetic spectrum. It does provide a considerable amount of information, providing trained personnel are available for the interpretation of photographs.

There is a greater scope for the recognition and differentiation of ground information if colour sensitive film is used. A hand held colour photograph taken from a satellite flight and covering an area of Central Australia previously surveyed and mapped by the Division of Land Research, showed a high correlation between the map and the photograph, but in some respects, the space photograph showed detail which had not been discerned on the black and white aerial photographs available for the survey. Were such colour photographs taken at satellite height available for the whole of Australia, the construction of a broad land type map of the whole country would be very considerably facilitated.

The scope for detection by photography is further extended by the use of films sensitive in the near infra-red section of the spectrum which provides a different array of photographic responses.

Multi-band photography extends the possibilities still further. This is the use of a number of film and filter combinations to sample different parts of the visible and near visible spectrum. By projecting the several images through different combinations of filters, it is possible to separate many features visually which are not discernible in single-band photography.

At longer wave-lengths in the infra-red through to radar, photographic methods are not possible, but the reflected radiation can be sensed and recorded electronically on tape by devices which automatically scan the land surface, giving continuous spatial coverage. The output from these can be displayed on a TV screen or recorded as permanent images on film and used in a similar way to photographs, but at present these methods have considerably lower resolution than direct photography.

Because different materials at the earth's surface have different reflective properties, the use of a wider array of wave-lengths than in the photographic range extends the possibility of differentiating objects and of sensing different attributes. For example, if the human eye

Plate 1 — Part of central Australia taken from the Gemini V satellite at an altitude of 140 miles with a hand-held Haselblad camera loaded with ordinary colour film. This black and white halftone has been made from a colour print.

can differentiate between ten shades ranging from white to black as presented by panchromatic photography, the use of three different wave-length bands with equivalent differentiating powers would provide 1000 possible combinations from which to select individual signatures of particular land surface features.

Other forms of sensing may also have application to land resource studies, for example, gamma ray and other techniques being used in geological and mineral studies.

The usual visual interpretation of photographs provides information directly but is dependent upon the skill of the operator. The process is slow and becomes more so with the use of multiple imagery. Attention has, therefore, been directed to automatic techniques of image interpretation. This has been applied

Plate 2 — A photo of a land-system map of the same area. This map, typical of these produced by the CSIRO Division of Land Research has been compiled by studying a series of aerial photographs and after months of laborious field work.

both to images derived from direct photography and from electro mechanical scanning devices.

Some of the achievements recorded to date are impressive. For example, at Purdue, an airborne multi-band optical mechanical scanner has provided an automatic computer print out of areas of different agricultural crops. A 90% success in identification has been claimed. The value of such methods is at present restricted to situations such as in agriculture where discrete areas of very uniform characteristics can be identified[14]. It is conceivable that similar processes could apply to the recognition of landscape patterns, but it is unlikely that a high degree of precision could be achieved without a considerable amount of ground control.

Another method of extracting data from actual photographs is the use of automatic stereo scanning equipment to record terrain height data. Such data can be analysed to give quantified land form descriptions.

The present state of the art of remote sensing is illustrated by the fact that the United States proposes to launch in 1972 an Earth Resources Technology Satellite (E.R.T.S.) and at a later date a satellite to record data for agricultural use only[15].

The agricultural satellite will be placed in an orbit which will make it synchronous with the sun. Apart from carrying various multispectral sensing devices, this satellite will have data collecting equipment which will be able to interrogate fixed ground installations, designed to transmit information on such items as water levels of lakes and streams, atmospheric data, surface temperature, soil moisture, or snow depth.

Providing these new sensing devices can be developed to give adequate resolution, the possibilities for observing agricultural phenomena from satellites and aircraft become enormous, particularly if multiple satellite systems are eventually established, permitting more frequent observations. Some of the possibilities being examined are: the collection of census data for crop areas; progress observations on crop condition and yield estimates; recognition of some soil nutrient deficiencies; monitoring soil moisture conditions, and irrigation requirements; weather forecasting; the progressive observation of the development of drought conditions and fire hazard conditions; observation of rainfall patterns and the monitoring of vegetation condition in pastoral areas; early warning of the development of crop or forest disease and insect infestation; soil erosion changes; water leakages from irrigation channels and from aquifers to the sea; surface water resources; and information that could be of value in detecting mineraliferous areas, as well as a whole range of oceanographic observations related to marine resources and phenomena.

The possible significance of these techniques can be illustrated by two examples, one at the global and the other at the national level. Any single nation having the facility to acquire prior knowledge of world crop situations by satellite records would have a distinct advantage in the marketing of its own primary produce over countries lacking this facility. Australia would not want to be one of the latter. The second relates to possibilities of drought monitoring. One important contribution to the management of drought situations would be to provide the primary producer with as much predictive information as possible — short term weather and water supply forecasts, estimates of the likely feed situation in his own and other areas some months ahead, likely supplies of fodder or grain reserves, price projections for feed and livestock — in fact, about all factors which he might have to manipulate should a drought develop. The automatic monitoring of soil moisture changes and vegetation condition over the agricultural and pastoral regions of Australia could make an important contribution to such predictions.

The automatic recording by satellites of information transmitted from equipment located in remote areas, difficult of access and supervision, opens a special array of possibilities in the field of water resources and the agricultural environment.

Although existing evidence encourages the belief that all the observations I have mentioned will be possible and could become routine in the long term, there are many technological and analytical problems yet to be solved. Further, the magnitude of the ground installations and systems necessary for receiving, storing, processing and distributing data would be considerable and expensive. The advantages of the several methods will need to be related to the difference in cost and the importance of the extra increment of information or extra speed of data collection they provide compared with existing methods. It is yet too early to predict the extent to which satellite recording will become a routine operation, or what observations will be most usefully and most economically made. It can be regarded as certain that practical applications will be in operation from aircraft or satellites within the next decade and will contribute to the study and monitoring of the world's land resources. In the near future, black and white and colour photography, including photography from satellites, appear to offer the most promise for land resource purposes.

One further comment is appropriate. Should Australia participate in satellite systems, it is likely to be on a nation wide use basis, rather than for purely State or regional purposes, and this would have implications to the kind of programme which is developed and how this is organized.

Conservation

In recent years there has been a growing consciousness throughout the world of the impact that man is now having on resources and his own environment. The concept of the deterioration of the environment is not new to Australia. Agriculture of the 19th Century was a very fragile system. It lacked the stabilizing influences of superphosphate, trace elements, improved crop varieties, nitrogen fixing pasture legumes, and well tried agronomic practices. Barton in 1895 listed five "Aspects in which the environment had deteriorated: Extirpation of plants and animals, removal of checks of natural increase of others, ringbarking, silting of rivers and large floods from increased run off, and erosion of channels"[(3)]. Reference to the ill effects of settlement on natural resources and the need for conservation policies were referred to repeatedly. They became subjects of raging controversies following the disastrous droughts during Farrer's later wheat breeding days and concern for these matters contributed to land reform changes during the first half of the 20th Century.

Emphasis in present day discussions is often on the destructive influences of man's use of resources and of technology, but we should not lose sight of the fact that man has achieved many positive gains. Examples of the natural environment being made better and more productive are widespread in Australian agriculture, especially in our mixed wheat-sheep husbandry systems and in the improvement of pastures in both temperate and tropical regions. Positive achievements need to be appreciated, the circumstances of their success understood, and their use extended. All the effects of man have not been destructive, although we have not failed in that respect either.

Conservation means more than mere preservation. Rational utilization of resources is the keynote to modern land conservation concepts. Intrinsic in this positive approach is the concept of the ecological management of land resources. The ultimate objective in the rational use of land, so far as is practicable in a complex community, and taking into account the needs of the future, as well as the present, is to have different land types used for the purposes to which they are best adapted and most appropriately allocated, e.g. to forests, watersheds, arable lands, pastoral lands, mixed agriculture, irrigation, urban and industrial areas, recreation lands and tourist reserves, and special reserves selected to preserve adequate samples of the inherited natural biological capital of the nation. A second objective, with the same reservations about practicability, is to have lands managed in a way that not only maintains or improves productivity or other virtues of value to the community, but also avoids detrimental repercussions on other areas or other resources. There is a third objective involved in ecological management, namely that associated lands should be both allocated and used in a manner which capitalizes on the profitable interactions between them.

It is necessary to realize, however, that there is now an existing pattern of land use which has resulted from natural limitations, historical accidents, past economic influences, and previous land tenure policies. It cannot easily be disturbed without good reason. Changes to a more desirable pattern must necessarily involve many conflicting interests. It is here that it becomes so necessary for firm attitudes to be taken on what represents the best use of land in the community's interest and in the interests of future communities. If such attitudes are to be generally acceptable, a background of sound information about all types of land and their significance and behaviour under different circumstances becomes essential.

Unfortunately, many land use developments involve changes which are irreversible, or at least are very difficult or costly to reverse. For example, once arid and semi-arid regions are severely degraded by over-grazing, it can take decades or even centuries for a stable vegetation and surface soil to be re-established. Forest unnecessarily cleared may take many decades to regenerate. Changes in surface and subsurface water regimes following land development can degrade land permanently by the accumulation of salt or by other repercussions. The effects of establishing a large dam and irrigation scheme are equally irreversible and engineering works, which unnecessarily scar the landscape, can destroy its aesthetic as well as its phyical qualities. This irreversiblity further emphasizes the importance of knowing and taking into account the consequences of any projected change in the use of land.

Future pressures on land

As Australia develops and its population increases, and one hopes, as the world demand for our products also increases, there must be increasing pressure on land. Although experiences such as the recent surplus of wheat production illustrate the reserve potential that we have at present to meet increasing production demands, sooner or later, these reserves will diminish.

Pressure on land will not be evenly distributed. It will arise, as it has already arisen, around our urban areas and along our recreational coast lines. Australia has a greater proportion of its population in big cities and near the coastline than almost any country. It is important that this large proportion of the people should have accessible land to meet the requirements of life, other than merely a place on which to build a house or factory and that future populations should have the benefit of wise planning by this generation.

In rural areas the better use of land already in use will necessarily have a major place in land utilization policy, but less productive lands or undeveloped lands with new potentials, and lands not being used for the most suitable purposes, will need to be examined in order that we may know where economic and social advantages lie. Greater competitiveness can be expected in world markets, partly because of greater production available for export from both developing and developed countries, as the application of modern technologies is extended, and partly through the effects of regional and other international marketing arrangements. This and the increasing costs of inputs will create conditions which will make more efficient use of land imperative. This will involve the more deliberate choice of land for particular purposes, as well as refinements in the improvement of production and land use methods. Continued intensive research into the more obvious factors in agricultural, forestry and water production, will be necessary, but in addition, we can expect to see a rapid development in the study of whole ecosystems in an attempt to arrive at an understanding of those factors which are most responsible for variations in productivity, and to identify the factors which are most vulnerable or amendable to managerial control. From this it would be expected there would emerge a better judgment of which total systems are most productive, most flexible and most persistent, and which can contribute best to regional and national land use objectives.

Land resource data requirements

Although studies associated with the development of Australia's agricultural, forestry and mineral resources have produced a mass of information which has been necessary for the progress of these industries, much of the information about land resources of this country has been collected in different ways for different purposes. It will need re-examination to make it compatible for comprehensive land resource inventories. Moreover, there are still marginal and little developed areas requiring survey in order to provide the same kind of systematic knowledge which is now available for much of Northern Australia and Papua and New Guinea.

In higher rainfall areas, there are large tracts of country which need to be re-assessed in terms of their water resource value, their forest and forest management value, and for the identification of those parts of the country which might be better used for other forms of production.

The three-quarters of Australia classified as arid or semi-arid is particularly susceptible to increased land use pressures. Fortunately, in spite of some examples of severe and irreversible degradation, on the whole, these resources still remain intact, although somewhat battered in places. The delicate status of many areas could easily be upset if there are moves towards achieving bigger returns before there is an accompanying advance in knowledge of how to control and manage these land resources.

It will be important to understand the dynamics of the native vegetation in relation to climatic crises and grazing practices, if its productivity is to be maintained. The planning of this research and the extrapolation of its results are dependent upon a basic knowledge of land types within each region.

The dairying areas of the three eastern States constitute regions in which considerable readjustment of land use is inevitable and is proceeding. While this can happen as a result of the ruthless impact of economic pressures on individual landholders, a co-ordinated, uniform type of land resource information could hasten and guide the transition from one form of land use to another in a more comfortable manner.

Areas occupied by other well established industries may also face similar reorientation in the future as world supplies or consumer demands vary and relative economic advantages change. Fore-planning, based upon the anticipation of the need for such adjustments and a fuller knowledge of the possibilities and consequences of proposed readjustments to land itself, will almost certainly have to assume a greater place in agricultural policy. The increased variety and choice of technological advances will require more precise knowledge of land resource condition, responses and capabilities.

The impact of seasonal variations, of natural crises such as drought, floods and fire, economic shifts in market demands, costs and prices, and the consequences of less than optimal land management practices, all have impacts which are felt far beyond the local, or even State, scene. As the more demanding situations of the future develop, it might be expected that the economic latitude to choice in the use of land will decrease, both locally and nationally. There will be an increasing need for more precision in making decisions concerning the allocation and management of land resources and in the adjustments that will have to be made to meet changing situations. There will be greater need for these decisions to be made in the total national context, and therefore, for land resource information to be available in a form that is sufficiently uniform for synthesis over the whole country.

Many authorities at the regional, State and national levels are concerned with different aspects of the problem, including those concerned with agriculture, forestry, water resources, soil conservation, nature conservation, tourism, road development, town planning, and local affairs. Collectively these bodies are responsible for our land heritage. Close liaison, active co-operation and joint planning between all these authorities will become more and more important in the future.

Australia's effective response to these challenges would be assisted if entrepreneurs and local, State and national decision makers have access to a wide variety of information related to land use and the changing agricultural scene. Apart from precise knowledge of the distribution of different kinds of land resources in the nation, their current state at any time, and their potential, there will be need for ready access to the most up-to-date physical, biological, and economic information related to land use. The variety of information and decision making necessary will be many times greater than at the present time. If there is to be flexible and continuing revision of decisions directed towards optimal land resource strategy and management, it will be necessary to make progressively more use of the rapidly advancing technologies of data collection, storage, and analysis. Some applications of automated data collection will become essential and this will almost certainly involve, amongst other things, the use of satellite facilities organized on a national basis. Furthermore, the mass of data to be handled may well require the use of comprehensive data banks and computer operated interrogation and data analysis systems.

It is appropriate to conclude with a reference once more to the man we honour tonight, William James Farrer. The trend of this address has led far away from the simple land survey instruments and the pioneering approaches to land characteristics of his time. Today science is dealing with problems and complexities of a kind that could not have been dreamt of by William Farrer. It is a compliment to the stature of this man that, in spite of the technological and scientific gulf between his days and ours, we still place such a great importance on his contributions to Australian science.

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