Agriculture and The Environment in Western Australia

Proceedings of a meeting held
in Perth on
10th October 1979

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PREFACE

This publication contains the proceedings of a meeting held on October 10th 1979 at the Western Australian Institute of Technology. A similar meeting in 1978 dealt with rehabilitation of mined lands. The success of that event gave the impetus to this one. It was considered that, in view of the large effects agriculture has had on Western Australian land surfaces, a juxtaposition of 'agriculture' and 'the environment' could attempt to clarify perceptions and reconcile differences by way of informed discussion. To that end participants at the meeting were able to read the contents of these proceedings beforehand, and the authors were given a special brief to present their points with the understanding that discussion would be a major component of the meeting.

This publication may be seen therefore as the second of a series of environmental perspectives on resource issues related to land surfaces in Western Australia.

It should be stressed that the meeting was not conceived as a vehicle for placing agriculture 'in the dock'. On the contrary it was seen as a forum for presenting the position today of controversial aspects pertaining to agriculture and the environment. People on the land have held a special position in Western Australia, recognized by our system of representation. The long term prosperity of the State must lie in the wise use of its renewable natural resources. We look to people on the land as custodians of these resources. Our farmers and graziers have built up expertise in cropping and grazing systems to the extent where some well-tried methods may now be described as traditional. Nevertheless change is continually complicating management procedures. In addition to the vagaries of the climate such extraneous forces as markets and technology continually intrude into calculations to alter variables in industries where ideally the operators would prefer to control as many variables as possible.

At a time when transport costs are rising more and more urbanites are looking to rural areas for living space. Closer settlement nowadays entails many more problems than in earlier times and it is probable that some patterns of settlement could result in all groups being losers. Simultaneously the productive rural enterprises continue to grow in size and contract to close family units in terms of population density. What can only be seasonal labour opportunity is increasingly rejected by urbanites who seek mythical job security in times of job scarcity. These contrasts provide a background to most of the topics included in this volume.

Rural communities are showing real concern for the environment. More and more groups are forming where local people set aside time to examine the natural features of their environment *e.g.* the Kojonup Ecological and Environmental Protection Society and the Naturalist Clubs operating in a number of districts. Local initiatives from such groupings will have an increasing effect on decision-making and administrative controls deemed necessary in the broader public interest.

Acknowledgements

It is with pleasure that acknowledgement is made of much useful advice from officers of the Department of Agriculture regarding the planning of the meeting.

Fellow members of the organising committee are also thanked for their generous co-operation. These were:

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W.J. Lorimer	The Chamber of Mines of W.A. (Inc.).
N. Orr	Department of Conservation and Environment.
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Grateful thanks are expressed to all those who contributed to these proceedings and most especially to those who were approached rather late.

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JOHN E.D. FOX
BENTLEY, W.A.
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AGRICULTURE AND THE ENVIRONMENT IN WESTERN AUSTRALIA

Edited: J.E.D. Fox

CONTENTS

"PAPERS"

Is There a Clash Between Agriculture and Environmentalists?

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Introduction

In this opening paper to our meeting on Agriculture and the Environment I am not going to deal with facts in an authoritative way but rather to introduce the issues to be discussed in this meeting. It appears to me that we should be thinking about these issues under two headings which could be described as:

a. Agriculture versus the natural environment.

b. The quality of the environment of the agricultural landscape.

In discussing these topics I will mainly emphasize the land occupation aspects of agriculture. The area of land used by agriculture represents by far its greatest impact on the environment.

Agriculture versus the Natural Environment

Let me say at an early stage that I believe agriculture has had an enormous effect on the environment of Western Australia. Few people would deny this, the problem comes in trying to put value judgements on the nature of the effect agriculture has had.

There is no objective way of comparing an agricultural environment with a natural environment. There can only be a census of subjective judgements.

If you compare the natural landscape, before man's interference, with the agricultural, or man-manipulated landscape, what are the differences? Generally there is a greater variety of higher plant and animal species in the natural environment. Man tends to destroy competitors to his crops and animals whereas natural competition is not fierce - subtle differences are often adequate to allow species to co-exist. There is usually a greater biomass present at any one time in the natural landscape. This is because the harvest is lower. The agricultural landscape may easily have a higher productivity.

Having made some factual observations about the differences and recognized that it is difficult to make an objective comparison, how, then, can they be compared? Someone concerned with human welfare could well conclude that both agricultural and natural landscapes are desirable and the proportion of each should be determined by the relative need of the total community for a higher population and/or more food and income versus a need for more 'bush' for any of a variety of recreational purposes.

Other people more inclined towards conservation might wish to retain sufficient 'bush' to ensure that no plant or animal species would be made extinct by man's agricultural activities because this plant or animal may one day be of some use or interest to man.

A real conservationist will question whether man has any right to dominate so much of the surface of the earth as he already has, to the detriment of many other living species. Thus such a conservationist would wish to see substantial areas of all types of habitats set aside for minimum interference from man's activities.

A superficial discussion of the subject of agriculture and the environment makes it apparent that the topic is a difficult one, dominated by the frame of reference in which the topic is examined.

Until recently I believe any discussion of agriculture and the environment would have started from the anthropocentric assumption that clearing virgin land for additional agriculture was a 'good thing'. This may still happen but the assumption is being more frequently challenged. The causes of the change are many. One is an awareness of the rapidly diminishing area of natural environment, another is the fast growing recognition being given to the rights of 'minority' groups. The recognition is spreading from disadvantaged human minorities to seal puppies, whales and one day, maybe, to bobtail skinks. Another very important cause of change is the growing belief that continuing to supply additional food for a continually growing human population merely defers the day or nature of the ultimate limit to human population.

If we look briefly at the impact of agriculture on the environment in Western Australia, what has happened? Two striking changes come readily to mind. The low rainfall forest of salmon gum and gimlet which occupied the loamy calcareous soils of the 300-400 mm rainfall zone has been almost completely cleared for agriculture. Areas left uncleared are too small to properly represent the indigenous flora and fauna of this area. The whole indigenous ecosystem disappeared in the fifty years, 1910-1960, before anyone thought seriously about national parks. An even bigger impact may have been wrought on the pastoral areas where an area of more than 50 million hectares has been subjected to overgrazing by the introduction of sheep and provision of water with no management of grazing pressure.

If some person were to think that these changes were bad they might ask what is being done or what could be done to ameliorate or reverse these changes. The answer is that the pastoral areas can be, and for economic reasons perhaps will be restored and we will hear more about this later. However, it seems very unlikely that the forest will ever be restored in any substantial area of the wheatbelt. All that can be done there is to ameliorate the effects of agriculture that the community of the time considers to be undesirable. This brings us to the second of the two issues I outlined initially.

The Quality of the Environment of the Agricultural Landscape

The environment of the agricultural landscape can never be a complete substitute for the natural environment. However, an agricultural landscape can satisfy many purposes other than agricultural production. It can be aesthetically pleasing, it can support a wide variety of indigenous animals, particularly birds, and it can allow many elements of the original flora to be retained. However, to do these things requires effort on the part of the landholder.

Unfortunately for the environment farming in Western Australia is new, economically viable, and highly profit oriented. The farmer is strongly motivated towards using his own land for his own purposes, to make money. There is very little feeling among farmers in Western Australia that they are responsible for a national resource and should consider its value to the rest of the community and to the future. It is suggested that such a change of attitude will only develop very slowly and to bring it about more quickly we need either controls, incentives, education, social pressures or perhaps a combination of these.

The most obvious bad features of the agricultural landscape result from excessive clearing and grazing. If sheep and rocky hills, waterways, saline flats and deep white sands were left uncleared and protected from grazing there would be a negligible effect on farm production and little effect on farm profit other than the cost of extra fencing. A great deal could be done to reduce the bad image of agriculture in the eyes of environmentalists if these steps were taken. Farm landscapes would look better, erosion damage to productive land would be reduced, and bird life would be enormously increased on farms. Some farmers already do these things.

Another unfortunate feature is the tendency of many farmers to see 'the bush' as their enemy. This results in a desire to clear, thin out by grazing, or burn bush, quite apart from any desire to use it for agricultural production. This results in one of the most harmful effects of agriculture on the natural environment; this is the excessive burning of uncleared country. Farmers tend to set light to adjacent reserves 'to thin out the vermin' or to 'reduce the fire risk'. Farmer members also persuade authorities responsible for such areas to adopt excessive burning policies. An exaggerated idea of the benefits of frequent burning of uncleared land seems to have become established.

Conclusion

There is a clash of interests between agriculture and the natural environment.

In the past in Western Australia this clash has always been resolved in favour of agriculture. This may not be so in future but it will depend on how much pressure is exerted by continuing population increase on supplies of food and other agricultural products.

This clash between agriculture and the environment can be minimized in two ways. Firstly by setting aside really large areas like the Fitzgerald Reserve to represent natural environments in an undisturbed condition. Secondly by improving the quality of land management on existing farms.

A Review of the Causes of Salinity in South Western Australia

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Abstract

Salinity, whether of soils or streams, is a consequence of clearing, mostly for agriculture, in south western Australia. It results from the replacement of deep rooting perennial native plants by shallow rooting annual crops or pastures. The summers are hot and dry, so that limits to the growing season are set by the duration of the season of winter rainfall, and by the amount of soil water stored in the shallow root zone. Under these conditions, the change in vegetative cover results in a decrease in transpirational loss of water from the soil, and the excess percolates through deeper layers, carrying salts stored there, to lower lying areas or to groundwater. The consequences are salinisation of soils in certain landscape situations, and increased salinity of rivers and streams.

Salinity of soil and water following agricultural use of the land is a common enough problem elsewhere in Australia and in the world, especially where irrigation is practised in arid areas. But salinity associated with dry land agriculture is seldom so widespread as it is in south western Australia. This paper examines the combination of factors which give rise to this. While no one factor alone is unique, the combination of them found here is certainly most unusual.

Introduction

This topic has been reviewed in various contexts in recent times. Last year "Search" published a number of articles on salinisation, including one from Western Australia (Mulcahy 1978), in an issue largely devoted to desertification, and the topic was discussed again at the Hydrology and Water Resources Symposium in Perth last month. I have drawn freely on the papers presented by my colleagues at that Symposium, particularly Hurle and Johnston (1979).

Causes of Salinity

Landscape History

The landscape of the Archaean Shield area of the southwest is an extremely ancient one (Johnstone *et al* 1971), conforming in many respects to the Davisian concept of a peneplain. Thus it has low relief, ineffective drainage systems, particularly in the inland areas, and deeply and extremely weathered soils which are therefore very infertile and deficient in major and minor nutrient elements. The glaciations which in many other parts of the world effectively removed weathered materials by ice action, or buried them beneath fresh glacial and periglacial deposits, here produced merely climatic fluctuations involving periodic expansion and contraction of the inland arid centre at the expense of the more humid marginal areas. Thus the old soils persisted, and now support natural ecosystems uniquely adapted to them. These adaptations are many, and are only beginning to be understood (*e.g.* Main 1979), but one is especially important in the present context. That is the ability of the native vegetation to fully utilise the abundant winter rainfall and to survive the almost rainless and hot summer period by exploiting the soil's capacity to store water.

Climate

The climate is a Mediterranean one, characterised by cool, wet winters, and hot dry summers. The winter rains bring with them sea salts in dilute solution, the inputs being as much as 150 kg ha^{-1} yr^{-1} in the high rainfall coastal areas, and falling to 30 kg ha^{-1} yr^{-1} or less in the drier interior (Hingston & Gailitis 1976). Thus we have a situation in which in winter there is a substantial input of water and solutes, and a capacity for them to move within the landscape, either to groundwater or to lowlying landscape situations. But only a small proportion escapes from the system since the inland drainage lines seldom flow. In summer, the concentration of salts in surface water increases by evaporation, most obviously in the playa lakes, and the perennial native plants continue to transpire water while it is available, leaving the salts to accumulate in the soil.

Soil Conditions

The oldest landscape elements carry deep lateritic soils characterised by surface materials up to 6 m or more in thickness which are sandy, and transmit water rapidly. They overlie dense pale coloured clays, the so called pallid zone, which may be a further 30 m or more in depth. Hurle and Johnston (*loc. cit.*) quote figures for saturated hydraulic conductivities of these materials of 2 m day^{-1} for the surface soils and 10^{-2} m day^{-1} for the pallid zone. Thus water can move rapidly in the upper parts of the profile, but only very slowly in the deeper subsoils. The groundwater table, usually saline, is found at some depth in the pallid zone.

These soils contain appreciable quantities of salts. They are stored mainly in the subsoil pallid zone clays, with the greatest amounts usually above the water table level. Dimmock *et al* (1974) have published depth functions of the amounts of salt in the soil profile, and their variation with topographic position and rainfall. In general the amounts stored vary from 10^4 kg ha^{-1} in higher rainfall areas to 10^6 kg ha^{-1} in the lower.

In younger landscape elements the lateritic profile is truncated or totally removed, and the soils are podsolic or duplex types with sandy surfaces over clay subsoils. Where pallid zone materials remain there is still significant salt storage in the landscape.

Only where major landscape elements, for example the Avon Valley downstream of York, are cut below the level of lateritic weathering, are the soils relatively salt free, and such areas form only a very small proportion of the total landscape.

Processes of Salinisation

Clearing for agriculture, leading to permanent removal of the native vegetation over large areas is the dominant land use leading to salinisation. Other practices, such as open-cut mining, or sylvicultural thinning, which also affect the water and salt balance of catchments, make some contribution, though the effect may be temporary. In all cases the extra water remaining in the soil is redistributed both horizontally and vertically.

The lateritic uplands occupy a large proportion of the landscape and tend to have few defined stream lines. With their permeable surface soils they must therefore constitute the major intake area for water, and the processes of its redistribution following clearing the lateritic soils is important in the salinisation process. In the surface materials, lateral flow and its duration will be increased, as well as the vertical fluxes of water, which will be relatively small, to the underlying pallid zone. Despite its low hydraulic conductivity however, the latter has within it "preferred pathways" such as old root channels (Hurle & Johnson *loc. cit.*), which carry water relatively quickly downwards to the groundwater, so that its level rises and it may intersect horizons above it with large accumulations of solute. The groundwater concentration is thus increased, and discharge from it to drainage lines is also increased due to a greater head of pressure. Rising saline ground waters may intersect the land surface, giving rise to saline seepages and areas of saline soils.

On the duplex soils in the valleys below the lateritic upland, a different process is also involved. Following clearing, in run-off on the soil surface, or at the interface at shallow depth between sandy surface and subsoil clay, water moves laterally, leading to waterlogging in lower landscape situations, where solute concentration by evaporation can lead to salt scalds.

Neither process necessarily excludes the other, and particular occurrences of salinity may be due to a combination of both. In general, salinisation of soils and streams is more prevalent in lower rainfall areas, where potential for evaporation is higher, salt storage in the landscape greater, and leaching potential lower. In higher rainfall areas, the balance between increases in water and solute losses from catchments may be such that although the result is an increased yield of both, salt concentrations remain below acceptable limits.

Conclusion

Agricultural development in south western Australia has had widespread environmental effects, among which salinisation of soils and streams must be one of the most serious. So serious is it that it constitutes a real threat to water supplies, and consequently the State Government has implemented policies to minimise the effects. On land controlled by the State, proposals for alienation of Crown Land are referred to the water supply authorities and to the Department of Conservation and Environment. On freehold land in catchments forming actual or potential water supplies, legislation has been introduced to control clearing by farmers. The guidelines under which the legislation is administered are based on a catchment classification and zoning derived from a consideration of the factors I have outlined above (Sadler & Williams 1979).

Basically, the problem arises from under-use of available water by the agricultural systems presently practised. That is, a supposedly scarce resource is not being fully used on the farm, and the consequent increased yield cannot, in most cases, be utilized as a water supply because of its contamination by salt stored in the landscape. This suggests an important question for your consideration. The under-use of water by today's agricultural systems must be common to much of southern Australia's agriculture, even in areas without salt stored in the landscape to act as an indicator or tracer of the changes induced. Can the agricultural systems be changed to give both increased production, and at the same time avoid its adverse effects on water supplies?

References

Dimmock, G.M., Bettenay, E. and Mulcahy, M.J. (1974). Salt content of lateritic profiles in the Darling Range, Western Australia. *Aust. J. Soil Res.*, 12, 63-69.

Hingston, F.J. and Gailitis, V. (1976). The geographic variation of salt precipitated over Western Australia. *Aust. J. Soil Res.*, 14, 319-335.

Hurle, D.H. and Johnston, C.D. (1979). On the physical basis of salinity in the Darling Range of south western Australia. Institution of Engineers Hydrology and Water Resources Symposium, Perth, 10-12 September 1979.

Johnstone, M.H., Lowry, D.C. and Quilty, P. (1973). The geology of south western Australia - a review. *J. Roy. Soc. W. Aust.*, 56, 5-15.

Main, A.R. (1979). The Fauna. In O'Brien, B.J. (Ed.) 'Environment and Science', 77-79. (Univ. of W.A. Press: Perth).

Mulcahy, M.J. (1978). Salinisation in the southwest of Western Australia. *Search* 9, 269-271.

Sadler, B.S. and Williams, P.J. (1979). Salinity management and land use changes for south west rivers. Institution of Engineers Hydrology and Water Resources Symposium, Perth, 10-12 September 1979.

Current Research On Salinity

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Abstract

The main aim of the paper is to provide an account of current research in progress in Western Australia into various aspects of soil and stream salinity by Government Departments, tertiary institutions and private companies.

The paper also briefly reviews the extent of soil and stream salinity problems in Western Australia and describes early research work on soil salinity in particular.

Introduction

The purpose of this paper is to review the research activities in progress in Western Australia related to problems of soil and water salinity. As background to this coverage, I believe it is desirable firstly, to briefly indicate the extent of this State's salinity problems and to note the earlier research efforts.

Extent of Salinity Problems

Soil Salinity In The Wheatbelt

Historically, it was recognised as early as the 1920's, that soil salinisation developed following the clearing of the native vegetation for agriculture. Patterson (1917) predicted that salt problems were likely to develop in the the Salmon Gums area and Teakle (1929) reported that farmers on 29 properties in the wheatbelt estimated that 3.1 *per cent* of the total area of their farms was salt affected.

In more recent times, saltland surveys have been carried out in 1955, 1962 and 1974 to provide farmers' estimates of the total areas of land affected by salt, but which had previously been used for crops or pastures (Burvill 1956, Lightfoot *et al* 1962, Malcolm and Stoneman 1976).

In 1955, the estimate was 73,504 ha (0.5 *per cent* of cleared land) and, in 1962 it was 123,591 ha (0.68 *per cent* of cleared land). By 1974 there were 167,294 ha of saltland in Western Australia which had previously been used for crops or pastures. The area represented 1.17 *per cent* of all cleared land but in the Northern Agricultural Division the proportion of saltland to cleared land was 1.67 *per cent*. In two shires it was up to 4 *per cent*.

The 1974 saltland survey results undoubtedly showed further increases in the area of salt affected land in the agricultural areas of the State. However, comparison of the 1962 results with those for 1974 disclose many apparently anomalous results on a shire basis and casts doubt on the reliability of many of the figures presented.

A similar survey was repeated in March 1979, but, to date, no results are available. However, it is anticipated that the area affected will have increased further.

In addition to the areas of once productive land which have become salt affected, there were reported to be a further 377,945 ha of naturally salt affected land in the form of salt lakes *etc.* within farm boundaries in the agricultural areas (Burvill 1956).

Stream Salinity

The second and equally serious salinity development is the deterioration in water quality. It is now estimated that about 36 *per cent* of the surface water resources of the South West region of W.A. have increased in salinity to such an extent as to seriously limit their usefulness. In the last few years Governments have acted to limit further deterioration of these water resources by severely restricting further clearing for agriculture on five river catchments in the South West (Anon 1979).

Irrigation Areas

In addition to the dryland soil salinity problems and stream and river salinity increases, there is also concern with the control and prevention of soil salinity development in irrigation areas. Included here are the Government controlled areas in the Swan Coastal Plain, private irrigation schemes, and the Carnarvon irrigation area.

Early Research Work

The first report of any consequence concerning saltland emanating from the Department of Agriculture was by Teakle (1928, 1929). Teakle reviewed overseas and local work on soil salinity and presented his own analysis of how the problem occurred in Western Australia. It is of interest that by 1929 it had been recognised that the salt problem was at least partly due to cyclic salt brought in with the rainfall, that salt problems were more prevalent in areas where rainfall was low, that its occurrence was influenced by topography and soil type and that the removal of the natural vegetation was the basic cause of salt encroachment.

The following two decades marked a period of intense soil survey activities in the agricultural areas. The prediction of Professor Patterson in 1917, concerning the likelihood of salt problems developing in the Salmon Gums area, proved to be substantially true and the resulting problems with saltland led to extensive soil surveys in the Salmon Gums areas, the Lake Brown area, the Lakes District, the East Pingrup-Lake Magenta area and the 3,500 Farms Area to the south east of Southern Cross. Soil surveys led to a much more detailed understanding of the extent and nature of the salt problem in Western Australian soils. In the main these surveys were concentrated in the areas of low rainfall and are therefore particularly relevant to the development of the salt problem in the wheatbelt.

From about the mid 1950's onwards, both the Department of Agriculture and C.S.I.R.O. became involved in hydrological studies in wheatbelt areas. These studies demonstrated that highly saline ground water existed at shallow depths beneath salt affected wheatbelt valleys and that the water was under pressure and tending to flow to the soil surface (Smith 1962, Bettenay *et al* 1964).

During the 1960's a major effort in research by the Department of Agriculture in relation to salinity was directed towards the introduction and selection of productive salt tolerant perennial plants for use in the wheatbelt areas of the State. This programme was undertaken to increase productivity on salt affected areas considered too saline to devote to any other land use. The research is currently at the stage where seed of selected species is being multiplied and mechanised harvesting and sowing methods devised (Malcolm 1974).

Current Research on Salinity

For the purposes of this paper, I have included various research programmes commenced since about 1970 under the term "current research". The last 10 years, have seen a great upsurge in salinity research directed towards the higher rainfall areas of the State, particularly as a consequence of the development of bauxite mining in the Darling Ranges, woodchipping in the lower South West and accelerated deterioration of potential and actual surface water resources in these areas. I have outlined the various projects being pursued by the institution listed below, and have endeavoured to make the list as complete as possible.

C.S.I.R.O.

Research work by C.S.I.R.O. on salinity covers the general areas of catchment hydrology, evapotranspiration measurement, drainage, agroforestry and reforestation.

*Catchment hydrology - Investigations are in progress in three localities, (Bakers Hill, Jarrahdale and Collie). At Bakers Hill, on the C.S.I.R.O. Yalanbee Research Station, a paired catchment study involves stream gauging and groundwater monitoring of the effects of clearing for agriculture (Williamson and Bettenay 1979). In the Collie River catchment area, a detailed study involving five catchments with complete salt and water balance calculations is being carried out and a variety of clearing strategies are being investigated.

This project is a joint C.S.I.R.O.-P.W.D. investigation.

The Bakers Hill and Collie catchments were initially instrumented in 1968 and 1974 respectively.

At Del Park, near Jarrahdale, C.S.I.R.O. has been pursuing, since 1973, a catchment study of surface and groundwater changes following bauxite mining.

*Evaporation measurements - C.S.I.R.O. researchers have in recent years adapted the ventilated chamber technique for evapotranspiration measurement to enable data to be obtained from forest trees as well as smaller native plants and introduced crops and pastures. Such information is needed to enable calculations to be made in regard to what proportion of already cleared areas might need to be replanted to various types of plants to increase water consumption sufficiently to reduce stream salinity (Greenwood and Beresford 1979).

*Drainage - At Yalanbee Research Station, investigations are in progress to provide data on the effectiveness of various forms of deep drainage in reducing soil salinity (Bettenay 1978).

*Agroforestry - The possibilities for some form of combined agricultural and forestry operations on the same area of land are being studied in the upper Helena River catchment. Measurements are also being made of the effects of these combinations on ground water patterns. The work is being conducted in collaboration with the Forests Department (Anderson and Batini 1979).

*Reforestation - Reforestation studies are being conducted in three rainfall zones of the Murray River catchment on sites upslope from salt affected areas. The growth rates and water use of different tree species and changes in groundwater levels are being measured in detail. The project also includes screening of tree species for salt tolerance.

Virtually all these studies include the gathering of data on soil salt storages, which are being collated together with information acquired by other researchers.

Department of Agriculture

The main salinity research programmes are concerned with salt tolerant plants, evapotranspiration measurement, catchment hydrology (including reforestation), and studies of salinity in the irrigation areas (Anon 1978a).

*Salt tolerant plants - A continuing programme of introduction and testing of salt tolerant perennial shrubs and grasses has been pursued since the early 1960's. Parallel to this screening work there has been a lengthy series of trials aimed at developing improved field establishment techniques for the selected species. At present, efforts are being directed towards the creation of specialized seeding machines for these plants and to the development of seed harvesting machinery in order to encourage the application of research results to farm practice. Work is also proceeding to obtain quantitative data on the grazing value of salt tolerant species.

*Evapotranspiration measurement - This work complements C.S.I.R.O. investigations, by extending the range of plants being measured (crops, pasture, salt tolerant species and native plants) to the general wheatbelt areas.

*Catchment hydrology - Selected catchments at Wongan Hills, Newdegate and Esperance are being studied to quantify the various components of the salt and water balance. Particular emphasis is currently being directed towards acquiring more data on unsaturated hydraulic conductivities. All data are to be used to develop a landscape hydrology model for wheatbelt areas. The hydrological work also includes a study of the effect of partial reforestation of a cleared catchment (east of Brookton) on groundwater levels and extent of salt affected soils.

The Department of Agriculture is also monitoring the effectiveness of interceptor banks in alleviating salt affected land as proposed by Whittington (1975). A detailed investigation of the effect of such interceptor banks is being conducted on an area near Quairading.

*Salinity studies in the irrigation areas - The Department of Agriculture is involved within the irrigation areas of the State in a number of studies related to the influence of the increasing salinity of Wellington Dam water on irrigation soils. All the studies are under the auspices of the Irrigation Commission and in co-operation with the Public Works Department. Firstly, a water and salt balance study is being conducted on an area of 200 ha of land covering portions of three farms. Here, it is possible to measure quite accurately the amount and salinity of the irrigation water being applied, the amount and salinity of drainage water leaving the area in surface drains, the rainfall and its salinity and also depths and salinity of ground waters occurring beneath the area.

At Benger an irrigation pasture experiment is being conducted to determine the effects of Wellington Dam water on pasture production. At this site it is possible to apply both the relatively fresh water from Stirling Dam and the relatively brackish water from Wellington Dam to irrigated bays within the same experimental area.

A third study continuing within the irrigation areas is in co-operation with both the P.W.D. and the Geological Survey of W.A. Here, a network of bores has been installed to monitor the depth and salinities of underground water tables within the irrigation areas.

A further trial just commencing is to study the effectiveness of a number of forms of drainage in removing salt and in encouraging improved yield and composition of irrigated pasture.

A considerable amount of detailed study has taken place on irrigated areas at Carnarvon in relation to salt and boron contents of irrigation waters and associated soil and plant toxicity problems.

Forests Department

The Forests Department's research in the Yarragil catchment near Dwellingup, the Mundaring and Murray catchments, and in the Donnybrook sunklands include study of the effects of various forest management practices *e.g.* intensity of logging, on salt flow from the catchments. In addition, the Department has some 65 arboreta in agricultural areas including many species of known salt tolerance or capacity to transpire water and from which much useful physiological data is being obtained. In particular, new arboreta have recently been established on farmland areas east of Collie to further this area of knowledge.

Public Works Department

As mentioned earlier in this paper the Collie catchment hydrological studies are being conducted jointly by P.W.D. and C.S.I.R.O. In addition, the Public Works Department has become heavily involved in quite broadscale testing of various reforestation strategies using different tree species on cleared areas which already have a salinity problem. This work is being conducted in collaboration with the Forests Department.

A further P.W.D. salinity study is that being conducted at Batalling Creek, east of Collie, to assess the value of a system of interceptor drains designed by Mr. H.S. Whittington to improve stream salinity (Anon 1979b).

Alcoa of Australia (Ltd.)

Because of Alcoa's involvement in bauxite mining in the Darling Ranges, the company's environmental group are involved in continuing research projects related to salinity. In particular, their officers have been active in co-operative modelling studies of the effects on water quality of bauxite mining in the catchment of the South Dandalup Dam (Peck *et al* 1977) and in studies aimed at identifying areas of low salinity hazard (Slessar *et al* 1979). The company is also involved in studies of techniques for revegetation after mining, both on its own account and in co-operation with the Forests Department.

University of Western Australia

*At the Faculty of Engineering detailed studies are proceeding into the salinity and temperature stratification of reservoirs (Imberger *et al* 1978). Work of this nature on the Wellington Reservoir has enabled the development of a scouring procedure to remove some of the more saline water impounded in the dam.

*Laboratory work is commencing in the Department of Soil Science and Plant Nutrition in the Faculty of Agriculture to examine the infiltration and redistribution rates of water and salts in duplex soil profiles. The techniques to be used will include the use of a newly developed gamma ray scanning system. These studies will involve simulation of the upward movement of saline water under pressure through soil columns and the process of capillary rise from shallow watertables. The work will also aim to gather data on hydraulic conductivities and the role of preferred pathways in water movements in deep pallid zone material.

*Staff and students of the Geography Department have been active in studying the role of shallow subsurface water movements in relation to the development of salinity problems in the agricultural areas (Conacher 1975).

Western Australian Institute of Technology

Currently the Department of Physics is undertaking a survey and preliminary study of salinisation of soils and groundwater in an area near York. The study is largely the work of a postgraduate student and will add useful knowledge about an area lying between the main wheatbelt to the east and the Darling Range to the west, for both of which a considerable amount of data already exists.

Other Studies

Although the various projects briefly described above have been listed under individual institutions, I believe it important to draw attention to and emphasize the very considerable level of inter-Departmental and interdisciplinary co-operation which occurs within and between virtually all projects.

The reports of the Steering Committee on Research into the Effects of the Woodchip Industry and the Steering Committee on Research into the Effects of Bauxite Mining (Anon 1978b, Anon 1978c), illustrate this point very well. Between them, the two committees are responsible for twelve research projects involving most of the Departments and institutions listed above, plus the Geological Survey of W.A. and the Metropolitan Water Board. The projects cover salinity modelling, identification of areas vulnerable to salinity increase, paired catchment studies, small stream sampling studies, monitoring at stream gauging stations, groundwater monitoring, and rehabilitation studies.

Conclusion

The last ten years have seen the development of a considerably expanded research effort in Western Australia into the overall problem of soil and water salinity. Because of greatly increased public awareness and concern about the ramifications and implications of unchecked salinity increases, even greater Government investments in all aspects of salinity research are likely in the future.

References

Anderson, G.W. and Batini, F.E. (1979). Clover and crop production under 13-15 year old *Pinus radiata*. *Aust. J. Expt. Agric. Animal Husb.* 19, 362-368.

Anon (1978a). Annual Report 1978, Soil Conservation Service. (Western Australian Department of Agriculture).

Anon (1978b). Report by the Steering Committee on Research into the Effects of the Woodchip Industry on Water Resources in South Western Australia, April 1978. Dept. Conserv. Env. W.A. *Bulletin No.* 31.

Anon (1978c). Report by the Steering Committee on Research into the Effects of Bauxite Mining on the Water Resources of the Darling Ranges. (Dept. of Industrial Development, W.A.).

Anon (1979a). Clearing and Stream Salinity in the South West of Western Australia. Public Works Department. Document No. MDS 1/79.

Anon (1979b). Investigations of the Whittington Interceptor System of Salinity Control. Progress Report May 1979 Water Resources Information Note. (Public Works Department of W.A.).

Bettenay, E., Blackmore, A.V. and Hingston, F.J. (1964). Aspects of the hydrological cycle and related salinity in the Belka Valley, Western Australia. *Aust. J. Soil Science* 2, 187-210.

Burvill, G.H. (1956). Salt land survey 1955. *Jour. Agric. West. Aust. (3rd Series)* 5(1), 113-119.

Conacher, A.J. (1975). Throughflow as a mechanism responsible for excessive soil salinisation in non-irrigated, previously arable lands in the Western Australian wheatbelt; a field study. *Catena* 2, 31-67.

Greenwood, E.A.N. and Beresford, J.D. (1979). Evaporation from vegetation in landscape developing secondary salinisation using the ventilated-chamber technique I. Comparative transpiration from juvenile *Eucalyptus* above saline groundwater seeps. *Jour. Hydrology* 42, 369-382.

Imberger, J., Patterson, J., Herbert, R. and Loh, I. (1978). Simulation of the salinity structure in a reservoir of medium size. A.S.C.E. Hydraulics Division. Vol. 104, No. HT5 *Proc. Paper* 13773, May 1978: 725-743.

Lightfoot, L.C., Smith, S.T. and Malcolm, C.V. (1964). Salt land survey 1962. *Jour. Agric. West. Aust. (4th Series)* 5(7), 396-410.

Malcolm, C.V. (1974). Forage production from shrubs on saline land. *Jour. Agric. West. Aust. (4th Series)* 15, 68-73.

Malcolm, C.V. and Stoneman, T.C. (1976). Salt encroachment - the 1974 salt land survey. *Jour. Agric. West. Aust (4th Series)* 17(2) 42-49.

Patterson, J.W. (1917). Report to the Royal Commission on the Mallee Belt and Esperance Lands (Western Australia).

Peck, A.J., Hewar, R.A. and Slessar, G.C. (1977). Simulation of the effects of bauxite mining and dieback disease on river salinity. *C.S.I.R.O. Div. Land Res. Managt. Tech. Pap.*, No. 3.

Smith, S.T. (1962). Some aspects of soil salinity in Western Australia. (University of W.A. M.Sc. Agric. Thesis).

Teakle, L.J.H. (1928). Soil alkali I and II. *Journ. Agric. West. Aust. (2nd Series)* 5, 399-408.

Teakle, L.J.H. (1929). Soil alkali III. *Jour.. Agric. West. Aust. (2nd Series)* 6, 88-102.

Whittington, H.S. (1975). The battle for survival against salt encroachment at "Springhill" Brookton, Western Australia.

Williamson, D.R. and Bettenay, E. (1979). Agricultural land use and its effect on catchment output of salt and water - evidence from southern Australia. International Conference on "The Agricultural Industry and its effects on Water Quality", Hamilton, New Zealand.

The Salinity Problem of South-West Rivers and its Management*

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Abstract

The salinity problem of the South-west is reviewed in terms of available water resources to the region.

Catchment management in the form of clearing controls and partial reforestation are examined with consideration of costs and alternatives.

Introduction

The South-west of Western Australia is a region dependent mainly upon the modest water resources of rivers and streams draining from the south western corner of the Western Plateau. A number of these rivers have serious salinity problems or are at risk of developing them as a result of clearing native forest or woodland and a consequent slow release of salts which are stored in the soils.

Already some 22 *per cent* of the potable resources readily divertible to water supplies are developed. Furthermore, the region has no economic prospect of further supplementation from elsewhere. It is surrounded by a semi-arid area to which it exports water and the cost of supply from the remote Kimberleys could never compete with sea water desalination. As a consequence of the finite limits of regional resources, the growing level of demand, and isolation from other resources, the protection of both the developed and the undeveloped water resources from further degradation, has been emphasised in recent policy decisions.

Spatial Variation of Salinity Potential

In general, the susceptibility of a stream to salinity increase from the leaching of stored salts after clearing is related to soil conditions and to rainfall. Areas inland of the 900 mm rainfall isohyet are mostly highly susceptible and areas coastwards of the 1100 mm isohyet are usually not susceptible. The area between, the so-called intermediate zone, forms an area of irregular transition in which the salinity potential is highly variable from place to place.

The distribution of State Forest in relation to these zones of susceptibility is of great significance to protection of the water resources of the region. State Forest extends inland from the Darling Scarp to about the 800 mm or 700 mm isohyet.

General Effects of Salinity on Water Resources

In gross terms the total surface water resources of the region have a mean annual discharge of 6,100 million cubic metres (6100 x $10^6 m^3$). However only 2600 x $10^6 m^3$ *per annum* of these resources are divertible for water supply purposes and as much as 34 *per cent* of these divertible resources have been degraded by agricultural clearing to salinities in excess of 1,000 milligrams per litre of total dissolved solids (1000 mg l^{-1} T.D.S.). Only 47 *per cent* of divertible surface water resources remain fresher than 500 mg l^{-1} T.D.S., although before settlement most resources would have been so classified.

Table 1 illustrates the association between rainfall, clearing and salinity for 19 major rivers of the region which comprise 57 *per cent* of gross streamflow and about 70 *per cent* of divertible surface water resources. The resources excluded from Table 1 are mainly smaller streams draining from the scarp or coastal plain and in such cases would be fresh irrespective of clearing.

The rivers of Table 1 have been grouped in three reasonably distinct categories.

Group 1 includes those shorter rivers afforded the protection of being mostly in State Forest with only limited portions, if any, in agricultural (largely cleared) areas in the less than 900 mm rainfall zone. The 9 rivers tabulated in this group are fresh and mainly below 250 mg l^{-1} T.D.S.

Group 3 on the other hand contains rivers whose catchments extend well into low rainfall areas where considerable portions of their catchments have been largely cleared for agricultural purposes. The 5 rivers in this group are brackish to saline. Considering the large area of agricultural land in their catchments they would be extremely difficult to bring under control by present salinity management techniques.

Group 2 consists of an intermediate group of rivers whose catchments contain substantial proportions of forest but extend sufficiently inland to include areas of alienated land whose clearing is seriously detrimental to salinity. The 5 rivers in this group with a total mean annual flow of 720 x $10^6 m^3$ represent 12 *per cent* of the gross surface water resources and a higher proportion (20 *per cent*) of divertible resources. Because their salinity is precarious, these rivers have been the main focus of recent initiatives in salinity control.

Catchment Management Measures

In the early years of our settlement, when few

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* This paper is a slightly modified version of a paper presented at the Hydrology and Water Resources Symposium of the Institution of Engineers of Australia, Perth, September 1979.

Table 1. Major rivers of the South-west region.

River	Catchment Area above Damsite*			Average Annual Rainfall Range Across Catchment		Mean* Annual Salinity Level	Mean Annual Flow*
	Land Area (km^2)	Extent Inland (km)	Portion Cleared (*per cent*)	Lowest (mm)	Highest (mm)	($mg\ l^{-1}$ TDS)	($m^3 x10^6$)
1. Brunswick	213	40	25	1 200	1 300	230	78
Margaret	443	45	30	1 100	1 250	200	135
Harvey	380	45	-	950	1 300	200	113
Shannon	337	45	-	900	1 400	215	94
Preston	603	60	40	900	1 200	250	97
Donnelly	805	75	18	800	1 300	230	154
Deep	1 250	85	15	700	1 375	200	172
Serpentine	663	70	-	700	1 125	200	81
Canning	754	70	-	700	1 125	400	65
2. Denmark	650	55	16	750	1 075	570	31
Collie	2 830	100	23	600	1 300	750	
Warren	3 890	140	33	550	1 400	725	356
Kent	1 650	90	33	550	1 125	1 100	84
Helena	1 470	85	3	550	1 100	360	72
3. Hay	1 400	65	70	600	1 000	2 000	71
Murray	6 840	170	70	450	1 125	1 800	351
Frankland	5 800	150	60	400	1 400	1 700	183
Blackwood	20 500	280	85	400	1 050	960	771
Swan/Avon	119 000	500	75	250	875	5 000	418

* Data given is related to an existing damsite or to the furthest downstream location at which it would be practical to develop for water supply purposes.

of our water resources had been developed or were required, the deterioration through salinity was relatively less important than land development. Today, with the limitations of water resources more apparent and with large areas of land developed, the relative values have altered in favour of protecting the remaining fresh water resources.

The first major actions to result from the gradual shifting of values were in the early 1960's when bans on further land alienation were introduced in some catchments. Since the late 1960's research activities have been steadily intensified and in 1976 an Act of State Parliament introduced clearing controls (with provision for compensation payments) on the Collie catchment. This action on the Collie River was taken to protect Wellington Reservoir, the largest water storage in the South-west.

At the end of 1978 State Parliament amended the 1976 legislation to extend clearing control to the other four principal rivers shown in Group 2 of Table 1. Two of these, the Helena and Denmark Rivers are already developed for water supply. The other two, the Warren and Kent Rivers are considered important resources for future development.

As a consequence of clearing that preceded the controls of 1976, it is predicted that the mean annual salinity of the flows into Wellington Reservoir will rise to approximately 1100 $mg\ l^{-1}$ T.D.S. by the mid 1990's. This is far from satisfactory and it is necessary to take some further action to protect the quality of water supplied to the Great Southern Towns Water Scheme. As a consequence during 1978 it was decided to implement a programme of partial reforestation of the Wellington Dam catchment area.

Detailed planning for the reforestation programme is not yet completed, but a 10 year programme reaching a planting rate of about 2000 ha *per annum* is envisaged. The programme proposes a major review after 5 years and flexibility will be maintained to allow changes as experience is gained and as results of research come in. The programme is seen as an important pilot study for other areas.

Approximately 650 km^2 of the Wellington Dam catchment has been cleared. Of this, approximately 400 km^2 lies east of the 800 mm rainfall isohyet in a highly salt susceptible area. If salt leaching from this area was restored to original levels, by strategically located partial reforestation, salinity would be reduced from 1100 to approximately 400 $mg\ l^{-1}$ T.D.S. This is an idealised estimate but it is considered that a reasonable target salinity for reforestation would be below 750 $mg\ l^{-1}$ T.D.S. Not all cleared land will be reforested in areas under treatment but portions will be retained under agriculture. As far as possible planting will progress westwards from the upstream eastern extremity where groundwater salinities are highest. Land acquired through the processes of compensation for clearing control will be used for reforestation and supplemented by land acquired on

Table 2. Rivers subject to clearing control regulations.

River	Area of Catchment/ Water Reserve (km^2)	Alienated land			Mean Annual Flow ($m^3 x 10^6$)	Mean Annual Salinity Level			Approximate Net Cost of Clearing Control ($ x 10^6)
		Cleared (km^2)	Uncleared (km^2)	Total (km^2)		Present	Predicted Future		
							With Clearing Control	Without Clearing Control	
Collie	2830	650	350	1000	185	750	1100	1700	1.5 - 2.5
Helena	1470	37	38	75	72	360	360	700	2.5 - 4.0
Denmark	650	103	31	134	31	570	640	850	0.3 - 0.5
Warren	3890	1251	538	1789	356	725	1000	1400	2.5 - 3.5
Kent	1650	550	450	1000	84	1100	1500	2500	2.0 - 3.5

Note: Estimated costs are based on 1977 land values. Costs given are net, i.e. when holdings are purchased as a means of compensation it is assumed all cleared land, dwellings and other fixed assets are resold.

the open market.

Costs and Alternatives - Protection

The new clearing control legislation makes provision for compensation to land owners prevented from clearing. Table 2 gives an estimate of the net cost (land purchase + cash compensation - land resale) for each of the five rivers.

The cost of clearing control in the Helena catchment is relatively higher than for the other catchments reflecting land values in an area close to the Perth Metropolitan Region. For the other four catchments a combined net expenditure of between $6,300,000 ($6.3 x 10^6) and $10.0 x 10^6 achieves the equivalent to preventing an increase of 524 mg l^{-1} T.D.S. for their combined mean annual flow of 656 x $10^6 m^3$ of water. Net expenditures, between $9 x 10^6 and $14 x 10^6 would appear to be small for protecting these important rivers.

For the divertible portion of the resources (approximately 540 million cubic metres *per annum* total for all five rivers) the average cost of clearing control (allowing 10 *per cent* interest charges) is 0.17 to 0.26¢ *per* m^3 expressed as an increment to the potential cost price of water. In the case of the two major developed water sources namely the Collie and Helena Rivers the estimated costs are approximately 0.15¢ *per* m^3 to 0.25¢ *per* m^3 and 1¢ *per* m^3 to 1.5¢ *per* m^3 respectively when expressed in terms of presently developed supply rather than potential yield. These unit costs could be compared with the present average price (below cost) of 19¢ *per* m^3 for water supplied by Country Water Supply systems. Even if these estimated costs of clearing control prove optimistic and some escalation occurs, there are no proven economically competitive measures for maintaining the quality of the developed sources. In the case of the undeveloped sources, normal discounting of future costs and benefits would affect these cost comparisons but the actions on clearing control have been supported by considerations of environmental responsibility.

Costs and Alternatives - Restoration of the Collie River

The cost of restoration of the quality of the water flowing into Wellington Reservoir depends on the target salinity level. If 40 *per cent* of the 400 km^2 cleared area east of the 800 mm isohyet is reforested and the remainder left in agriculture the cost would be in the region of $10 x 10^6 to $14 x 10^6.

Order of magnitude cost estimates of alternatives to partial reforestation on the Wellington Dam catchment have been made. A study was made of the feasibility of diverting any of the saline streams in the eastern regions by pipeline out of the catchment. The three most promising diversions together would result in a reduction from 1100 down to approximately 750 mg l^{-1} T.D.S. at a cost of $24 x 10^6 or more. There would be a reduction of approximately 10 *per cent* in yield and it is likely that disposal would present serious problems. Other diversions to further improve the quality become less and less cost effective.

The cost of desalination to restore the quality of Wellington Reservoir would be an order of magnitude higher than saline diversions. To improve the quality of the full yield of 100 x $10^6 m^3$ *per annum* would entail capital costs of approximately $75 x 10^6 to $125 x 10^6 plus approximately $30 x 10^6 *per year* operating costs with a 15 *per cent* loss through blowdown. Treatment of the 10 x $10^6 m^3$ domestic supply portion would be proportionately less but would be far from comparable with the cost of developing an alternative source of supply.

Conclusions

With the introduction of clearing control, action has been taken to protect the quality of the 5 remaining rivers of the region that contain areas of uncleared alienated land, the clearing of which would have resulted in a significant increase in salinity levels. All other rivers of any appreciable size, are in areas not susceptible to salt leaching, are protected by being largely within State Forest, are not economically feasible for clearing control, or are already too saline to have any forseeable potential as water supply sources. Costs of clearing controls are very low in comparison to costs of alternative measures but for some rivers have the disadvantage of incurring financial and social costs today for benefits which will be realised only in the future.

The technique of partial reforestation of a catchment to restore water quality is essentially untried and the benefits cannot be accurately assessed on present technical knowledge. However, provided reforestation achieves what appear to be reasonable expectations it is superior to presently available alternatives. This partial reforestation of Wellington Dam catchment will provide experience and contribute to the sum of knowledge necessary to enable a full assessment of the cost, in dollars and in effects on agriculture; and to assess the time that would be required to restore the quality of presently saline rivers or streams.

As the South-west region develops there will inevitably be an increase in demand on the rivers of the region from two directions. On the one hand there will be the need to develop more rivers and streams for water supply purposes and from the other direction will be the demand to preserve rivers in their natural state for ecological, aesthetic and recreational reasons. Inevitably these demands can only increase the need to preserve quality where possible and to continue present efforts to develop improved techniques for rehabilitation.

References

The following documents give specific information relevant to this paper.

Public Works Department of W.A. Clearing and Stream Salinity in the South-West of Western Australia. *Public Works Dept. of W.A.* Document No. MDS 1/79, July 1979.

Public Works Department of W.A. The Salinity Problem of South-West Rivers. *Public Works Dept. of W.A.* Pamphlet, September 1979.

Public Works Department of W.A. Salinity and Water Quality. *Public Works Dept. of W.A.* Pamphlet, September 1979.

Public Works Department of W.A. Salinity and the Water Balance. *Public Works Dept. of W.A.* Pamphlet, September 1979.

Public Works Department of W.A. Collie River Salinity Control. *Public Works Dept. of W.A.*, April 1979.

The Problem of Overstocking in Pastoral Areas

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Abstract

In Australia as a whole, the arid and semi-arid zones occupy about 75 *per cent* of the total land mass and the pastoral areas are located within these zones. In W.A. about 38 *per cent* of the land mass is given over to pastoral pursuits and falls within the definition of the arid zone within which rainfall is often inadequate and not conducive to landscape stability. It is often variable in intensity and spread and only the hardiest perennials persist under these conditions and are likely to be killed off in less favourable years if subjected to overgrazing.

Droughts of varying intensities and duration are regular features throughout the arid and semi-arid pastoral areas of Australia causing further economic problems to the industry and contributing to the instability of an already fragile vegetation which is an integral part of the landscape and of the eco-system.

Control of domestic livestock and vermin and careful regulation of grazing are basic to successful pastoral area management if long-term productivity is to be maintained and landscape stability preserved.

The foundation of the pastoral industry lies in the carrying capacity of the land and its associated vegetation. Permanent reduction in the base resource means a permanent loss to present pastoralists, to Governments and, more importantly, to future generations.

Introduction

Grazing by domesticated animals on pastoral properties in arid environments has been permitted and encouraged in most pastoral regions throughout the world and almost without exception has led to overuse, pasture degradation, reduced productivity, accelerated run off, increased erosion and, in extreme cases, deserts.

Bare and severely eroded country is not uncommon throughout the pastoral areas of the world and Australia is no exception. Particularly in our northern pastoral areas there is evidence of widespread pasture degradation, changes in botanical composition of pastures, reduced carrying capacity and soil erosion of varying severity (Fitzgerald 1976).

Traditionally, pastoral pursuits in Australia have been relegated to areas of low and erratic rainfall, often on areas of less fertile soils, where conventional agricultural cropping would be too risky due to inadequate and unreliable rainfall. Periodic droughts are recurrent features of the arid and semi-arid pastoral zones and from time to time have caused catastrophic stock losses and heavy financial losses to pastoralists.

In prolonged droughts severe damage has been recorded in both stocked and unstocked areas but it is generally accepted that over-stocked areas suffer the worst vegetation damage and severest stock losses. The Kimberley region enjoys a reasonably assured rainfall and is less prone to drought damage than the remainder of the pastoral regions of W.A.

Productivity of the arid zone in terms of animal production is primarily dependent upon the pasture components available and these are mainly determined by climate, soils and management although rainfall and length of growing season are major factors in determining pasture quantity and quality.

Stability within the arid grazing ecosystem is largely determined by the susceptibility of the dominant plant species to grazing and trampling, drought and fire. Good pastoral management seeks to maintain a productive equilibrium between animals, plants, soils and water and while this can be achieved, it is not easy and is certainly not inherent in the arid zone.

Accumulated evidence from the pastoral areas as a whole suggests that much of the damage to pastoral country has resulted from a build up in stock numbers during a run of good seasons and/or poor market conditions and the failure of pastoralists to reduce stock numbers quickly enough in less than average seasons or in the face of threatened drought. Quite frequently these are brave decisions but the weight of evidence suggests that owners who sell surplus stock regularly and reduce numbers quickly under adverse seasonal conditions are the ones who suffer less vegetation damage and are in a better position to recover both financially and ecologically when conditions improve.

The increased grazing pressure placed on edible shrubs, fodder-trees and perennial grasses in an attempt to maintain high stocking rates in adverse seasons or in the face of drought, has led to the destruction of the most important pasture component and valuable drought reserves on which stock depend when the annuals fail. Ironically, the shrub components are usually the slowest to regenerate with the return of good seasonal conditions.

Marshall (1970) has emphasized the importance of maintaining adequate shrub cover in an arid environment since it is such plants which reduce the erosive effects of wind, the principle eroding force. Unchecked wind continually causes landscape deterioration as it results in surface deflation, abrasion of the surface and destruction of existing vegetation through sandblasting. The erosive effects of water on unprotected surfaces and the importance of maintaining an adequate protective cover of deep rooted perennial species is well documented and recognised in almost every environment. The maintenance of a complete vegetative cover can virtually eliminate surface scouring and erosion and ensure landscape stability.

Accelerated erosion often results from the breakdown or removal of vegetative cover following overgrazing or fire and on this basis could be regarded as a result of rather than a cause of, a change in productivity. However, as accelerated erosion is usually associated with a soil nutrient loss and a reduction in soil permeability, which further limits secondary plant succession and establishment, it is difficult to draw a clear line of demarcation between cause and effect when it occurs. The question is purely academic as the net effect is the same.

Evidence of Overstocking in Other States

Considerable evidence has been accumulated by arid zone workers throughout the arid and semi-arid areas of Australia confirming that serious degradation has occurred on many land types. The inevitable conclusion from all these studies is that the major cause of pasture degradation, reduced productivity and subsequent erosion is the excessive removal of vegetative cover by consistent and continuous overgrazing by both domestic stock and vermin under marginal rainfall conditions. The effects of fire and periods of drought are additional factors aggravating an already precarious situation.

On an Australia-wide basis the introduction of grazing by both sheep and cattle into Australia's rangelands initiated a downwards trend in range condition (Perry 1970).

The degree to which changes in vegetation of the arid zones can be ascribed to grazing, as distinct from climatic effects is difficult to ascertain over the short term. Over the longer term the decrease in productivity in terms of animal carrying capacity may be associated with a recognisable decline in rainfall (Tucker 1975). However, in the absence of sufficiently long-term rainfall records to support the contention it appears logical to assume that overstocking has been the major cause. Graphed data (Perry 1968) on sheep and cattle numbers spanning four (4) states over the 100 year period 1860 to 1960 certainly supports the assumption.

The N.S.W. Royal Commission of 1901 in a comprehensive study of the drier areas in N.S.W. listed amongst the causes of pasture deterioration an ill-advised land tenure system and a gross over-estimation of the carrying capacity of the Western Districts.

Beadle (1948) made one of the earliest in-depth studies of pasture deterioration in Australia and his early observations in western N.S.W. still have application to most pastoral areas: "Since sheep are selective grazers, plants disappear in most cases in order of their palatability. Furthermore, perennials regenerate more slowly than annuals and consequently palatable perennials disappear before palatable annuals".

The decimation of stock population of semi-arid areas plus major changes in vegetation were inevitable because of the lack of knowledge of vital ecological controls (Beadle 1960).

In Queensland there is ample evidence of degradation and erosion in dunefields where areas have been subjected to serious overgrazing or burning followed by overgrazing, particularly in the spinifex-hummock grasslands or areas adjacent to watering points.

Blake (1936) drew attention to vegetation changes in Western Queensland and reported major deterioration in grazing lands brought about by the more or less complete disappearance of edible plants and the replacement of palatable species by less palatable ones.

Roberts (1972) also reported deleterious changes observed in the rangelands of the Western Districts of Queensland and suggested reasons for some of the changes. Overgrazing was an important factor but the possible effects of changing rainfall patterns over the longer term could not be discounted.

In South Australia serious degradation of saltbush pastures amounting to a national loss was reported by Dixon as early as 1892. The saltbush vegetation of arid South Australia, despite its hardy nature, had been so depleted by 1936 that only an estimated 25 *per cent* of the original cover still remained.

Ratcliffe (1937) reporting on erosion in the drier pastoral regions as a whole stated, "Whenever and wherever pastoral settlement is imposed on semi-desert areas with an uncertain rainfall the problem of the survival of certain components is automatically raised".

Western Australia

The pastoral industry in the arid and semi-arid areas of W.A. started in the 1860's, initially in the Pilbara-De Grey areas and along the Greenough and Murchison Rivers further south. Sheep were introduced into West Kimberley in the early 1880's while cattle became established in East Kimberley and as far West as Fitzroy Crossing by about 1885-86 (Wilcox pers. comm.).

Sheep numbers in W.A. rose to a peak of about 5.5 million in 1935 but have declined to about 2.1 million at the present time. Sheep numbers had reached a peak of about 320,000 in West Kimberley by 1940 but have now dwindled to insignificant numbers on one property on the extreme southern end of the Kimberley Division. At the same time, sheep numbers in the East Pilbara and Port Hedland Shires have been reduced to about 100,000 (Wilcox pers. comm.).

The dramatic drop in pastoral sheep numbers in W.A. closely parallels the decline in the Western lands of N.S.W. in the late 1890's and is consistent with the observations of Perry (1967) for all of the pastoral areas of Australia. Until quite recently the bulk of the pastoral area cattle in W.A. were confined to the Kimberley area where they now number about 800,000 head. Cattle numbers in other pastoral areas are increasing but still only total about 200,000.

Rainfall is considerably more reliable in Kimberley than in other pastoral areas of W.A. and the vegetation there has been better able to withstand the grazing pressure than in the drought prone areas further south. Despite this, there is evidence of severe pasture degradation and active soil erosion in Kimberley and current cattle numbers are considered too high for the continued maintenance of a stable landscape.

Following the disastrous 1935-39 drought the Royal Commission W.A. (1940) reporting on the effects of the drought stated "Some of the country has suffered permanent reduction in carrying capacity: some has been so seriously affected that it will take many years to recover. Evidence shows that many stations have been overstocked in relation to improvements and the losses in the drought have been accordingly, much higher". Sheep losses in the 1935-39 drought years were estimated by the Royal Commission W.A. (1940) at a staggering 4.18 million with an additional shortfall of 3.13 million in natural increase.

The following quotation from the Royal Commission of W.A. (1940) confirms the findings and observations from other Australian States.

'*In the past, owing to a run of good seasons, much of the developed country has been overstocked with the inevitable result that heavy damage and losses were suffered in those areas affected by drought. Quite frequently too there is a tendency for pastoralists to restock too quickly after the breaking of a drought in an attempt to recoup their losses thus causing further damage to the regenerating shrubs and perennial grasses that are slower to establish than annuals.*'

Two large river catchments in W.A. have been grossly overused for grazing purposes and have developed serious erosion problems as a result. The Gascoyne Catchment in the North-West grazed by sheep and the Ord River Catchment area in East Kimberley, grazed by cattle, typify the problem of overgrazing and are cited as fairly typical examples.

The Gascoyne River Catchment

Severe flooding occurred in the coastal township of Carnarvon in 1961, its nature suggesting excessive runoff from its catchment, which was confirmed by ground and aerial surveys.

The Pastoral Appraisement Board of W.A. commissioned a joint Agriculture-Lands Department survey team to examine in detail and report on the vegetation and erosion status of the catchment. Using the land system or 'rangeland type' approach the survey team recorded and reported on the pastures, degradation and erosion status and made recommendations covering proposed stocking rates and remedial treatment for each station within the catchment.

The severely eroded areas were mostly associated with erodible soils supporting palatable and desirable pastures that had been preferentially grazed. Continued overuse of these erodible areas under marginal rainfall conditions had degraded the catchment, reduced carrying capacity, induced erosion and created a flood hazard downstream.

A reduction in sheep numbers from about 417,000 to 239,000 was recommended to prevent further erosion and to assist in catchment rehabilitation.

The Ord River Catchment

Severe erosion of the Ord River catchment in East Kimberley posed a serious siltation threat to the proposed Ord River Irrigation Project where engineers calculated the silt load of the river at approximately 20 million tonnes *per annum*.

Erosion susceptible areas were defined by Teakle and Metcalfe (1944) and subsequently described in more detail by a CSIRO Land Research Survey in 1952. Aerial reconnaissance by officers of the W.A. Department of Agriculture in 1962 confirmed that most of the erosion was confined to one major group of soils developed over Upper Cambrian limestones, siltstones and mudstones and forming fine textured calcareous soils prone to wind and water erosion when stripped of vegetative cover.

The areas were amongst the earliest settled in East Kimberley and had been subjected to extremely heavy grazing pressure under a system of open rangeland grazing based exclusively on natural waters.

Approximately 1,000,000 ha was resumed, fenced, cleared of stock and subjected to cultural and reseeding operations as part of the Ord Regeneration Project. Remedial treatment was directed towards the basic cause of the trouble - removal of vegetative cover through overgrazing. Now, some 19 years after treatment was initiated, the programme is regarded as an outstanding success with mixed perennial and annual vegetation re-established, the landscape mainly stabilised, the silt load of the rivers greatly reduced and livestock being reintroduced under controlled and experimental conditions.

Regional Vegetation and Erosion Surveys

Following the initial success at Ord River and the lead set in the Gascoyne Catchment additional joint Agriculture-Lands regional surveys have been commissioned by the Pastoral Appraisement Board as part of an overall programme covering the entire pastoral region of W.A. to provide a complete pastoral resource inventory.

West Kimberley

The West Kimberley survey of 1972 by Messrs. Payne, Kubicki, Wilcox and Short recorded similar findings to those recorded for the Gascoyne catchment.

Pasture degradation was widespread with erosion evident along the over-used river frontages consistent with overgrazing by cattle and vermin (wallabies and donkeys).

A substantial reduction in cattle numbers was recommended for the affected stations, together with a major effort to reduce vermin.

Subsequent to the release of the West Kimberley report, a follow-up committee comprised of an experienced officer from Lands Department and Agriculture visited each station and reached agreement on future safe carrying capacities for most of the properties in the survey area.

Nullarbor Plain

A joint Agriculture-Lands survey of a portion of the Nullarbor Plain region by Messrs. Mitchell, Hacker and McCarthy was carried out in 1974. The remaining portion will be completed when new aerial photography is available. An interesting feature of this survey, in which very extensive areas of degraded country was examined and evaluated, was the fact that it had not been stocked.

Most of the degradation recorded could be attributed to the ravages of rabbits and wild fires. Heavy pressure of grazing by rabbits has seriously depleted the shrub population and prevented re-establishment. Reduced competition from shrubs has assisted the establishment and spread of annual grasses, providing fuel for wild fires which has further reduced the shrub population, creating something of a vicious circle.

Due to the difficulty of finding suitable stock water, the fragile nature of the vegetation and the unreliability of rainfall, most of the Nullarbor area surveyed is considered unsuitable for allocation as pastoral leases.

Ashburton Catchment

A similar survey of the Ashburton River catchment by Messrs. Payne, Mitchell and Holman was initiated in 1977. The field work has been completed but the final report has not been published. Once again there was ample evidence of pasture degradation and some erosion associated with over-use under marginal rainfall conditions.

'The Jennings Report'

An in-depth study of the Pastoral Industry of Western Australia by a committee under the charimanship of Mr. Brian Jennings has recently been completed. The final report, entitled 'The Present and Future Pastoral Industry of Western Australia - April 1979', is now available to the public.

Some of the recommendations made in this report will have far-reaching benefits and implications for the pastoral industry in W.A.

Conclusion

The proper management of arid and semi-arid pastoral lands should aim at the maintenance or promotion of a stable and productive landscape. The concepts of stability and productivity are inseparable as management objectives and any management system must be evaluated in terms of both.

Management decisions affecting landscape stability must inevitably influence productivity and in this context the call by Slatyer (1969) to develop management standards which maximise long term ecosystem stability rather than short term animal productivity presents a major challenge to pastoralists, land administrators, range ecologists and conservationists.

Control of stock numbers and careful regulation of grazing, including that by vermin, are basic to successful pastoral area management and the survival of the industry.

References

Beadle,N.C.W. (1948). The vegetation and pastures of western N.S.W. Dept. Soil Con. N.S.W., Sydney.

Beadle,N.C.W. (1960). Vegetation in the Australian arid zone. Proc. Arid Zone. Tech. Conf. Vol. 11, 4-1. Warburton, Victoria.

Blake, S.T. (1936). Notes on some pasture problems in Western Queensland. *Proc. Roy. Soc. Qld.* 47, 89:91.

Dixon, S. (1892). The effects of settlement and pastoral occupation on Australia upon the indigenous vegetation. *Trans. Roy. Soc. S.A.* 15, 195-206.

Fitzgerald, K. (1976). Management and Regeneration of Degraded Catchments and Eroded Pastoral Lands with Particular Reference to Range Reseeding F.A.O. Conservation Guide: No. 3 Conservation in Arid and Semi-Arid Zones.

Marshall, J.K. (1970). Assessing the protective role of shrub dominated rangeland vegetation against soil erosion by wind. In Proc. XIth Int. Grass. Cong. Qld. (A.N.U. Press: Canberra).

Perry, R.A. (1967). The need for rangeland research in Australia. *Proc. Ecol. Soc. Aust.* 2, 1-14.

Perry, R.A. (1968). Australia's arid rangelands. *Annals of Arid Zone* 7, 243:249.

Perry, R.A. (1970). Arid shrublands and grasslands. In 'Australian Grasslands'. (Ed. R.M. Moore). (Aust. Nat. Univ. Press: Canberra).

Ratcliffe, F.N. (1937). Further observations on soil erosion and sand drift. Pamphlet No. 79, C.S.I.R.O., Melbourne.

Roberts, B.R. (1972). Ecological studies on pasture condition in semi-arid Queensland. Unpublished Report D.P.I. Charleville.

Royal Commission (1901). Royal Commission to enquire into the condition of the crown tenants. Report and Summary of Evidence. Western Div. N.S.W. (Govt. Printer: Sydney).

Report of the Royal Commission W.A. (1940). Appointed to enquire into and report upon the financial and economic position of the Pastoral Industry in the leasehold areas in Western Australia. (Govt. Printer: Perth).

Slatyer, R.O. (1969). Preface to 'Arid Lands of Australia'. (Ed. R.O. Slatyer and R.A. Perry). (Aust. Nat. Univ. Press: Canberra).

Teakle, L.J.H. and Metcalf, F.G. (1944). Soil erosion reconnaissance of the Ord River Valley. 23/44. Vol. 1, W.A. Dept. Lands & Surveys.

Tucker, G.B. (1975). Climate: is Australia's changing? *Search* 6, 323;328.

Wilcox, D.G. and McKinnon, E.A. (1972). Report on the Gascoyne Catchment. Commissioned by the Pastoral Appraisement Board of W.A.

Government Involvement in Pastoral Practices

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Abstract

Present pressures on the Pastoral Industry are reviewed from the viewpoint of the pastoralist in terms of the effects of Government involvement. The industry provides a significant part of the Australian woolclip but producers face uncertain futures largely due to Government policies. Particular attention is paid to mining and its relation to pastoralism. Positive signs include recent recommendations on rangeland improvement and restructuring, and the benefits of Government services.

Introduction

It is, I believe, appropriate at a meeting such as this to discuss Government involvement, at all levels: Federal, State and Local in the Australian Pastoral Industry. Largely because of pressures that have emanated from outside, the industry has been under closer public scrutiny in recent years than at any time during its long and productive history.

It has always been my philosophy that pastoralists are in business in the same way as other businessmen in the community and should not expect preferential treatment provided they are not being seriously disadvantaged by Government policies. In fact the less Government involvement there is in my operation the better it suits me. However, because the Government is the landlord and the custodian, on behalf of the community, of Crown Lands a certain amount of Government interference is inevitable in the pastoral operation.

It is essential, for instance, for the Government to intelligently monitor the condition of rangelands held under Pastoral Lease to ensure that it is not being wilfully degraded. The majority of pastoralists these days, I believe, genuinely care for their land and have sufficient information and experience at their disposal to look after it. Human nature being what it is there will always be the speculator who is keen to exploit the resource, make a "fast buck" and get out. In this they are no different to the doctor who exploits medibank - very much in the minority and controllable! On the other hand of course one nowadays finds a vocal section of the community who would like to close up the whole country and turn it all back to the birds and animals - however, I suspect that these people would also enjoy steak and eggs for breakfast.

It is a function of Government to try to maintain an even balance between the two extreme viewpoints because if we are to maintain the living standards we have all come to expect the land has to be used. Equally if the land has to be made to produce for our purposes it obviously cannot remain exactly as it was - the important thing is to ensure that the next generation to inherit the land receives it in at least as good, and preferably better condition, than it is now. It is important also to set aside a reasonable amount of land in National Parks and Reserves for the general enjoyment of the community. One hears the opinion expressed that because the semi-arid areas of Australia are so fragile they should not be used at all for animal production. I believe that, because so much of this continent lies in the semi-arid zones, we have to judiciously use it if we are to justify our presence here and in fact I see it as a challenge to pastoralists and research scientists to ensure that the country goes on producing *ad infinitum* for the benefit of all.

Significance of the Pastoral Industry

Figures that I have from the B.A.E. indicate that there are 10,178 properties in the semi-arid zone which is 5.9 *per cent* of the total in Australia. These properties, however, run 53.2 million sheep or 36 *per cent* of the total flock - these sheep produce 240 million kg of wool which is 33 *per cent* of the Australian production and 9.5 *per cent* of the world's production of apparel wool. This is a very significant proportion of our wool production that is coming from the semi-arid areas and whilst the Australian economy these days, fortunately, is more broadly based and not so heavily dependent on the wool industry, it nevertheless, in my view, is an industry well worth preserving.

It is a means of effectively utilising land that is unsuited for other forms of agriculture and therefore because of the nature of the operation it is especially important that Governments appreciate the fact that the industry is just as sensitive as the land on which it is based.

Government policies, especially those cooked up in such artificial environments as Canberra, can have profound effects on people in the pastoral zone and the more so in recent years when rural incomes have been declining and an increasing number of pastoralists are becoming sceptical about the chances of present trends being reversed and are therefore questioning whether they have a future in the pastoral areas.

It is imperative, I believe, that Governments both State and Federal, and indeed the whole Australian community appreciate the present situation and act on it urgently. Pastoralists need to know the environment within which they will be required to operate in the future. This reflects a clear recognition that the rural sector forms part of a very interdependent Australian economy. Government action in other areas can often impose severe and quite unintended costs on the rural sector. Many rural problems are fundamentally caused by restricted and unstable market access overseas, rapid inflation in Australia, competition within the Australian economy through massive tariff protection to areas of manufacturing industry and rapid mineral development.

The pastoral industry in Australia has always faced climatic uncertainty with devasting droughts, floods, fires and other natural disasters. Huge inland distances and remote geographical location have accentuated transport difficulties. There have been wide and usually unpredictable fluctuations in commodity prices on the world markets.

For most of the last thirty years policies have been directed towards population growth and expansion and diversification of the domestic economy. In more recent years the rate of inflation has accelerated to quite unacceptably high levels with devastating effects to the rural economy. The dependence of people in remote areas on road transport makes them particularly susceptible to high fuel costs. The justification for lowering the cost of fuel in remote areas by public funding is to improve access to service facilities and thus promote equality of treatment of rural and city-based citizens: particularly in respect of basic services, health care and schooling, which are now readily available elsewhere but are declining in the more remote areas. The recent rises in the price of aviation gasoline have substantially raised the running costs of the average station - by about $2,250 *per annum* according to a recent survey conducted by the P.G.A.

The cumulative effect of these factors has resulted in a rapid rundown in the population of inland Australia making it increasingly difficult to service those that remain with reasonable road, mail, telephone and medical services.

Problems Facing the Pastoralist

Terms of Leasing

Assuming that it is desirable to have the pastoral areas occupied by competent people, there must be incentives and rewards to attract them.

Large areas of country with long term leases at low rentals are the first essential - these two conditions will help to attract the experienced lessee with the required capital and other resources to be successful.

This factor is more important now than ever before because of the very high capital involvement, the low return on invested capital, and the fact that it is no longer possible to get a quick capital return. In fact capital invested in a pastoral enterprise has depreciated during the past 10 years at an alarming rate which is in marked contrast to the position in the agricultural areas.

There seems to me to be no case at all for the retention of the million acre limit and it should be abolished. In my opinion the successful pastoral operation of the future will either be the relatively small, closely controlled family operation, *e.g.* father and son, or alternatively the very big operation embracing a number of properties in different districts to give an even spread across the seasonal conditions in the State or perhaps even in more than one State.

I have no doubt that unless there is a marked change in our terms of trade much of the pastoral country today will not stand the cost of development. In fact, much of it is not being properly maintained at present and we are relying heavily on the work and money put into the country years ago.

When one pays a rental and invests large amounts of money, one could reasonably expect to be able to generate an income and have some control over the country. At the moment we have neither: the country has been virtually incapable of producing an income let alone a return on capital.

We have very little control as is instanced by the activities of the Forests Department removing the sandalwood and mulga from properties as they see fit. A pastoralist is looking down the barrel if a mining company comes up with a mine on his property having no right to compensation for loss of country, production or income.

Whilst we have no wish to inhibit mining on Pastoral Leasehold Land there is a strong case for more protection for the pastoralist should a mine develop on his land and I believe that the Minister for Mines is working on this problem.

Mining Operations

The Mining Act makes a clear distinction between 'Private Land' and 'Crown Land' when compensation provisions are dealt with; Sections 123(2) and 123(7) and 125. In my view there is little difference between 'Private Land' and Crown Land that is held under Pastoral Lease.

I believe that there should be a separate section in the Act to deal with 'Crown Land held under Pastoral Lease' as distinct from unalienated Crown land. When one leases a house, a farm, or a car, providing the terms of the lease are complied with and the payments made on time, one is entitled to the peaceful enjoyment of the leased article and has security of tenure for the term of the lease. The pastoral leases are now current to the year 2015. We pay lease rents and comply with development and stocking conditions. However, should a mining operation develop on our land, or should part of the lease need to be resumed for any purpose, we are not entitled to compensation for the loss of the land, loss of production or lessening in value of the land adjoining the mining operation or the resumption.

It is quite unjust, in my view, to assume, as the Mining Act does, that the loss of land and production from Crown Land held under pastoral lease is less important than the loss sustained on 'private land'. It is well documented that a large mining operation cannot exist side by side with a pastoral operation without disruption to the pastoralist from town dogs, shooters, people running all over the lease leaving gates open and general disturbance of stock.

Sections 123(7) and 125 of the Act specifically preclude a pastoralist from recovering compensation for anything except fixed improvements that happen to be adjacent. No account is taken of loss of production and lessening of value of land and improvements over a much wider area. In effect, this leaves the pastoralist in the position where he has to rely on the sense of fairness and generosity of a Mining Company for the protection of his investment.

Abuse of station facilities, disturbance and theft of stock and equipment is so widespread that more protection by way of realistic penalties for offenders, is necessary. We recently had the spectacle of a judge in Perth advising the court that sheep stealing is no longer the serious offence it used to be.

Wild Dogs

A major problem facing West Australian pastoralists at the present time is the increasing pressure on sheep flocks from wild dogs. Whilst dogs, obviously, are not the sole cause of the present troubles in the industry, they certainly are a very significant factor when added to other difficulties such as escalating costs, an inadequate labour force and drought.

The recent crisis in wild dog control, in my view, has arisen largely as a result of the shortage of skilled labour on stations. The aboriginals, many of whom were skilled in the art of dogging have mostly left the stations for the towns and white doggers and experienced station hands are becoming increasingly hard to find. It is my opinion that in the years to come, no matter how high the wage may be, there just will not be the personnel available to go out into the back country to live the hard and lonely life of the dogger.

I believe, that with many other aspects of property management in the Pastoral Zone, new methods of wild dog control will have to be adopted to replace those which have worked in the past but are not possible in the future.

I therefore suggest that serious consideration needs to be given to the feasibility of erecting a Dingo Barrier Fence to enclose the proven sheep Pastoral Zone of Western Australia. Although the cost of a fence would be high a project such as this would need to be amortised over a period of no less than fifty years and would inevitably mean State and Local Government involvement.

Expensive barriers, in terms of cost to primary producers, are often raised to protect Australian secondary industry and the people employed in those industries - I refer to Tariff Barriers. An influx of wild dogs is equally as damaging to the Pastoral Industry as a flood of cheap imports from Asia would be to some secondary industries.

Positive Signs

The Jennings Report

The recently released report of the Pastoral Industry Review Committee led by Mr. Brian Jennings has highlighted some of the difficulties faced by the Pastoral Industry and has made recommendations designed to put the industry on a more secure basis to face the years ahead. Pastoralists will no doubt disagree with some of the recommendations made in the report but essentially, I feel, it is a soundly based document which recognises the need to improve the condition of the rangeland, to obtain more viable levels of operation by restructuring properties and to strengthen the administrative structure by the provision of a Pastoral Board embracing increased industry and technical representation. I think that the Committee are to be commended for the many hours of work they have put in examining in great detail all aspects of an industry that has been overtaken by rapidly changing conditions in the community. I hope that in this paper I have been able to draw attention tc areas where Government policies not directly related to the industry can still have a significant effect upon it as well as to those areas where Government involvement is necessary and desirable.

Government Services

Substantial benefits are derived for instance by Government funding of the Department of Agriculture and much information is being made available as a result of research work that is continually going on in the Pastoral Zone. The level of Government funding to the A.P.B. has been of great benefit to the industry in recent times of low wool and beef prices and adverse seasonal conditions.

An extensive A.P.B. research program involving the radio tracking of dogs has been going on in the Pilbara area which has finally demonstrated what we as pastoralists know all along - namely that dingoes do kill sheep. Whilst this may seem to be academic and a waste of time to some, it is important to have documented evidence that 'Dingoes do attack sheep' as there are strong moves within the community to have the dingo completely protected - this we have to prevent if our industry is to continue. It could of course be an argument in favour of a Dingo Barrier Fence - it being preferable to fence wild dogs out of sheep country rather than destroy them.

In my trip through the Eastern States last year to look at vermin control methods I gained the impression that the Pastoral Industry in South Australia appeared to be functioning well with a minimum of Government interference and I also gained the impression that pastoralists in that State do not have too much to complain about as far as the landlord is concerned. In N.S.W. it appeared that Government intervention in the Western Lands Division had resulted in pastoralists there being on properties that really are too small to be profitable under present conditions.

Conclusions

In conclusion I would like to re-emphasise that Government philosophy should be aimed at helping the individual to help himself, to keep restrictions to a minimum and to create a favourable environment in which the industry can progress.

Governments and the public at large have to come to terms with the fact that, because of changed economic conditions, the Pastoral Industry is not as strong as it once was. Policies may have to be implemented in the future that sound like heresy to present day Australians, for instance it may be necessary to operate a compensation scheme for the removal of livestock from a property for a time so that the rangeland can regenerate - such a scheme operates in the South African arid lands.

One aspect that does concern me is that the people who have the time to sit down and talk about the problems of the inland appear to heavily outnumber those who are prepared to get out into the bush and actually do something about it and the drift to the big cities continues - from here on we are going to need 'toilers and not talkers'.

Subdivision and Long Term Planning

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Abstract

Emphasis is given to techniques, other than simple subdivision control, necessary for long term planning of rural areas. Rural planning commences from an understanding of the quality of the land resource. There are considerable pressures to subdivide areas more suited for their resource use than for urban or rural-residential activities. In those areas close to Perth and country towns where land has little agricultural value and where subdivision would result in development contrary to the planning of the urban areas themselves, a considerable planning problem is faced in finding a use for the land to guarantee its management.

There is conflicting evidence as to the value of rural-residential or hobby farm uses in rural areas. Certainly servicing costs may result in considerable long term community commitments. However, most of the problems are evidenced on existing small, but inappropriate, subdivisions. Consequently the Town Planning Board has adopted a policy of guiding these small holding users to areas where land use conflicts are less likely to develop, where services can be supplied and where a degree of development control can be guaranteed. This policy has resulted in the creation of 70 Special Rural Zones in the past five years.

Various necessary techniques for the long term planning of rural areas remain to be developed in Western Australia. Some means of alleviating the impact of rating on farming enterprises and of securing landscape protection without public purchase are two areas in which new techniques will have to be developed in the future.

Introduction

Subdivision control remains the most common means by which rural areas can be planned but it is a notoriously imperfect tool. Subdivision is controlled on the assumption that certain land uses cannot be pursued on large land units. For instance, only one, or at most two, houses can be constructed on single subdivisions. In brief, by prohibiting subdivision one is controlling development without specifically saying so. This paper will not therefore address itself to subdivision policy alone for rural planning already does, and certainly in the future will, depend partly upon other planning devices which more directly control land uses and positively plan rural areas.

* The views expressed in this paper are those of the author and not necessarily those of the Town Planning Commissioner.

The long term planning of rural areas involves three primary considerations. Firstly, the need to manage certain resources essential for specific markets. This includes planning for the efficient supply of building materials for urban areas, the planning for the supply of fresh vegetables for specific communities, and the protection of recreation areas for the community.

Secondly, the need to safeguard resources essential to the national economy - such as good agricultural soils or areas of unique conservation or ecological value.

Thirdly, the planning for an efficient and economic growth in settlement patterns. This would include safeguarding areas for future urban expansion and ensuring that settlements can be economically provided with certain basic services.

Some of these considerations of rural planning have been in large part achieved by the actions of Government through public purchase of land (National Parks and Regional Open Space) or legislative provisions which restrict the despoilation of land best used for a necessary community purpose (such as the gazetting of water catchments and their subsequent control). However, some of these considerations are thwarted by subdivision pressure. For instance, land which could provide the most economic source of future building materials is in some cases coming under pressure for subdivision. Equally, scenic areas and coastal areas are subject to subdivision pressure as are the most valuable market gardening, vineyard and orcharding areas. Moreover, irrigated farmlands are undergoing development contrary to farm activity. The premature subdivision of land which will be required for the future expansion of Perth or country towns creates considerable additional long term costs to eventual residents and to public utilities, and the pressure to subdivide areas unsuited to residential living or difficult to service, creates continual additional costs at the local and the State level.

Subdivisions in Western Australia are determined by the Town Planning Board with an appeal to the Minister or an Appeal Tribunal. The Town Planning Board's policy for determining subdivisions stems from the considerations of rural planning stated above. This policy aims to safeguard various resources such as agricultural land, water catchments, mineral areas and conservation areas, and plan for genuine demands for various lifestyles by permitting subdivisions in suitable areas. However, at this time the policy has to partly rely on imperfect information. For instance, we do not know how much land we should keep for market gardens, building materials, or recreation. We do not know what the real demand for hobby farms and rural residential subdivision is. Moreover, the practice of applying minimum lot size criteria to certain rural uses does not in itself guarantee the viability of that use. For instance, applying a 20 ha minimum lot size to market gardening areas may do less to guarantee their future viability than would the surety that non-agricultural uses will always be forbidden in the area.

Thus, the Town Planning Board's current rural subdivision policy brings a wide range of considerations to bear on any subdivision application to ensure that the resources essential to the community are not sterilized or misused by premature subdivision. However, forward planning for the preservation of resources depends upon precise information not always available, moreover, it is not entirely best implemented by subdivision control alone.

The Problem Faced in Rural Fringe Areas

The Present Position

Throughout the world as urban areas grow, rural areas become disused and despoiled in their path. Farmers near urban areas regard the problems of *e.g.*: trespass from suburban communities; the effect of domestic animals harassing stock; and increasing taxes and rates, which are frequently based more on subdivision potential than on current use value; as being so severe that it no longer becomes worth farming their land. There are few dairy herds in the Metropolitan Region of Perth. In fact it is the Department of Agriculture's policy to encourage dairy farmers to locate outside the region.

How does one find a use for 240,000 ha of rural land in the Perth region? Land must be used to be managed and it cannot all be purchased for parkland since purchase and management costs would be prohibitive. Only a limited proportion of fringe areas are valuable resource areas. A substantial portion of our rural fringe land is not suitable for anything other than bush, or possibly the site for a house - this presents a vast land use planning problem.

Preservation of the Rural Resource

While it is accepted that a special effort must be made to preserve resource areas, totally effective means of securing these resources have not yet been adopted. For instance, the areas suitable for market gardening are not entirely occupied by people with any intention of market gardening and while zoning (the statutory specification of permitted land uses) can prohibit certain uses, it does not necessarily encourage desired uses. Zoning for agriculture does not in itself produce a farm any more than zoning for industry produces a steel mill.

It is increasingly argued that as the advantages of farmland close to the city accrue to the whole community in cheaper and fresher food and in the maintenance of a picturesque open landscape, it is the community as a whole who should help pay for its preservation. In fact 42 States in the USA have taken this view to varying degrees with the adoption of various programmes to alleviate the pressures to subdivide farming land by rate concessions, the purchase of the right to subdivide and develop or the outright purchase of valued rural lands. In Western Australia the Urban Farmland rating system is aimed at preserving farming land, but its operational inapplicability has not in itself resulted in significant preservation of the rural landscape and farmland that we benefit from.

Unfortunately for planners, no policy similar to that operative in the U.K., where the strategic importance of the limited land has resulted in strict development control throughout all farming areas, would be acceptable. In 1974 a Working Group on Rural Policy in Australia reported to the Prime Minister that: '*The physical quality of land for agriculture does not itself justify reserving its use for agriculture if it has a higher value for urban use*'.

In this context it is difficult to argue as is done in the U.K. that all agricultural land is sacrosanct. Australia's agricultural land appears almost infinite - with 77 million ha available for rain fed agriculture. The greater portion of this land is already developed and the development of new areas will incur greater fuel costs. Nevertheless it is difficult to counter subdivision arguments upon agricultural land value alone in the current political climate. Although the future role of agriculture in the economy of Australia is very attractive according to most informed sources, with increasing world demand particularly for meat and wheat, it is no easy matter to counter subdivision pressures with such hypothetical projections. Despite these difficulties a more selective approach to the preservation of identified crucial agricultural resources rather than blanket negative subdivision controls throughout rural zones needs to be initiated.

Other Resources

In addition to the difficulty of substantiating arguments in favour of maintaining agricultural land lies the difficulty of substantiating the need for mineral resources. We do know that the present cost of sand - an essential to urban building industries - doubles with an additional 20 km haulage. We also know that in Australia we have been sadly deficient in planning the exploitation of these resources. For instance, land suitable for the excavation of building materials is at such a premium near Melbourne that it sells for $500,000 per ha - compared with $150,000 per ha adjacent to cities in the USA. It is believed that the zoning of areas suitable for extractive industry may prevent problems arising in W.A., but such zoning in advance of requirements is yet to be undertaken.

Similarly, subdivision control alone is not the method by which the preservation of recreation and conservation areas in rural areas can be assured. Short of the direct purchase of land with a scenic or recreational value, a number of techniques could be made available - such as a grant to the owner to maintain walkways on his property, or a subsidy for the maintenance of a stand of trees. However, in Western Australia, direct purchase of land with a scenic or recreational quality is the only commonly accepted technique resulting in (for instance) the MRPA purchasing 11,000 ha in the Perth region with the continual public cost of maintenance.

Future Possibilities

Current subdivision policy is meeting with a certain degree of success in planning rural areas. In the long term it is clear that the planning of our rural areas will require techniques other than simple subdivision control. Public involvement in the safeguarding of various resources will become necessary and this involvement should ideally fall short of public acquisition. Subsidies to land holders in rural fringe areas either through subsidised or deferred rating or as payment for the amenity created by the open landscape may be a preferred technique, but this will have to be agreed upon and adopted before it is too late. In addition, the large areas with no definable public use will have to be provided with a use other than urban if our cities are to grow in a planned fashion at all.

Rural Residential Living

The problems associated with rural residential lots include:

absentee landlords - a source of other problems;

soil deterioration due to over stocking;

insufficient use of fertilizers;

too frequent cultivation;

cultivation of steep slopes;

lack of attention to weeds and pests;

straying stock;

inadequate firebreaks;

and, most important of all,

uneconomic service demands.

Often the problems stem from a small minority who have naively adopted a rural residential lifestyle and before long return disillusioned to the city. However, there is clear evidence that the numbers adopting this lifestyle are growing rapidly while the traditional farming community in many areas is dwindling.

Costs to the Community at Large

Small, inappropriate, old subdivisions have been bought up and developed by those seeking a rural lifestyle throughout Australia. The result has been a scatter of families across the country petitioning their local authority for better roads, for the collection of their rubbish and for other services. This has resulted in special legislation being enacted in Victoria to promote amalgamation of small lots in rural areas. The number of scattered small lots is smaller in Western Australia but most of the evident problems come from this source. The purchase and development of existing small rural lots for non farm activity is usually beyond planning control. In some cases the influx of rural residential dwellers on to these old inappropriate subdivisions has outnumbered the existing population who have even been voted off the Council. A scattered low density subdivision pattern does create problems and does cost the community more even if supplied with the most basic services. Although in W.A. we do not have the situation that has eventuated in Queensland where 200,000 subdivided rural lots supplied at great cost with water and roads lie unused, it is clear that the situation could arise where the development independently of all small rural subdivisions could result in a very heavy financial commitment to the whole community later.

There are a number of hidden subsidies to rural dwellers of which rural residential dwellers are direct beneficiaries *e.g.* a telephone costs perhaps ten times as much to install in a rural as an urban area yet the houseowner pays the same $120; SEC connections cost 55 *per cent* of the real capital cost to the utility; social services inevitably cost more; and school busing (which now amounts to 30 *per cent* of education budgets in some USA rural areas) is more expensive when settlements are scattered. It is argued by some that rural dwellers do not cost the community anything because they are self-sufficient in services such as water and sewerage. While this may be the case sometimes, it is certainly the experience of local authorities in W.A. that dwellers on rural residential properties have a quite different expectancy of services than do the traditional rural residents. A study in Serpentine-Jarrahdale confirmed that rural residential lot owners had a high expectancy of services.

Planning to Meet the Demand

In most States in Australia the perceived problem of small holdings has led authorities to attempt to stem the flow of people onto such properties. In W.A. it has been the policy of the Town Planning Board since 1974 to plan for the provision of rural residential lots. The basis of this policy is that by actually planning for a demand that demonstrably exists it is possible to provide some of the planning safeguards through development control provisions, while steering subdivision pressure away from inappropriate areas.

Thus, through the use of Town Planning Schemes and their associated zonings, areas for rural residential uses are set aside in suitable locations and developments are carefully controlled and monitored. The advantage of this policy was confirmed in surveys of small lot owners undertaken in 1977 and 1979 which confirmed that small holdings were used quite extensively by people actually living on their property or with the intention of doing so in the foreseeable future thereby providing land management rather than unused speculative blocks. The issue was therefore to ensure that these small lots were developed in suitable locations and in harmony with the environment. This is done by defining in advance acceptable uses, development control provisions and subdivision design with minimum permitted lot sizes. In addition responsibility for the supply of services is clarified.

The Town Planning Board has adopted a stringent rural subdivision policy whereby except in special cases subdivision is only permitted where a "Special Rural Zone" Town Planning Scheme is drawn up by the local authority. It is the policy of the Board to encourage the assessment of local authority areas prior to the adoption of any one Special Rural Zone so that the most suitable locations for rural residential uses are identified.

At the time of writing, 32 Special Rural Zones have been approved in the Perth Metropolitan

Region, with 852 lots created in these zones. Outside the Region, 38 Special Rural Zones have been approved and 1719 lots created. An informed guess would put the total lots available in Special Rural Zones at about 3,000 inside the Region and 3,000 outside by 1981. All these lots will be found on land without significant agricultural, mineral, water catchment or conservation value. In addition all the created lots will be subject to a level of development control formerly unknown in the rural areas of Western Australia.

Social Implications

From evidence compiled through periodic surveys in the Town Planning Department it is clear that planning for the demand for rural residential uses is being successfully tackled through the operation of the Town Planning Board's policy of approving carefully chosen Special Rural Zone Town Planning Schemes. However, the question for the future lies in establishing whether it is acceptable for rural wedges, without any definable resource value, to be uniformly subdivided down to a size desired by those in pursuit of a rural residential lifestyle.

The social consequences of relatively isolated dwellings could be severe in the long term, especially in association with increased fuel costs and its impact on mobility. Mothers isolated from family networks and friends as their husbands commute to work could be envisaged as a significant future problem resulting in a return to the city of rural residential dwellers with wasted investment within rural zones. Certainly we already know that Special Rural Zone lots are being purchased by people at a particular stage in their lifecycle. Most, according to a recent survey, are people in their 30's with 2 children desiring a place in a rural setting on which to run some horses for the children, but not desiring to derive their income from their property. Although there seems little evidence to justify the belief that the subdivisions will be held for speculative purposes, this may be because the demand is considerable and prices are high. If prices fall, a different kind of buyer could become involved in Special Rural Zones. However, so far the development of one and two hectare Special Rural Zone lots has resulted in the erection of expensive dwellings which could be the best imaginable safeguard against further subdivision.

Towards Improvements in Long Term Rural Planning

Alternatives to Rating

New solutions to the problem of safeguarding areas with significant resource potential will have to be found before long. At present rating is a major issue which is frequently used as an argument for subdivision. Rating on the basis of use, or on the rental value of the property for its current use, would certainly counter this argument. In return for this the community would expect some assurance that the landowner would not merely have his holding costs reduced and the speculative value of the land enhanced. Rate concessions could be initiated with some sort of capital gains tax or rating pay back to be paid on sale to act as a disincentive to speculate in land. Even this albeit expensive technique is no guarantee that the land most required for preservation would be secured. For instance, the rate deferment programme in California has attracted the compliance of landowners owning only 30 *per cent* of the land considered prime for agriculture.

Public involvement in the purchase of the development rights of land of resource importance will have to be considered. It should be noted that in some States in the USA, where it is practised, the development rights amount to 85 *per cent* of the total land costs. The cost is a heavy burden to the taxpayer and it can be questioned whether the authority would not be better paying the extra 15 *per cent* and owning the land outright. In any event the costs are staggering. Suffolk County in New York State set aside $21m for the purchase of only 1,570 ha of prime agricultural land. In Perth the purchase of land identified as prime for market gardens alone would cost roughly $75m (assuming an average of $5,000 per ha for the 15,000 ha so identified).

Landscape Preservation and Settlement Pattern

The preservation of areas of landscape interest is increasingly being seen as the right of the community. In the USA legal action has been taken on behalf of trees to prevent clearing to establish that trees, under United States law, have legal rights. In Western Australia, hopefully it will not be necessary to go to these lengths to ensure that significant landscapes are preserved. Zoning controls would be desirable along the whole length of the Darling Scarp to ensure that clearing was controlled and buildings developed in secluded locations. However, as yet such a step has not been taken except in isolated cases. The lack of separate funds to finance the subsidy of landowners for the maintenance of land of scenic value is unfortunate and in the future the expenditure of such funds may prove to be an economy when compared with the cost of outright purchase and continued maintenance practised at present.

Rural land with no clear resource potential will remain a planning problem in the future. To propose stringent subdivision regulations for this land even if acceptable would serve no long term planning purpose. The properties close to urban areas would become increasingly vandalized and remain a dumping ground and a fire risk. The planned rural residential development of these areas on a large scale with significant features protected and residences clustered near servicing points may be an attractive long term possibility in these areas if the demand for such a lifestyle continues at the current level.

Conclusions

Although local planners may bemoan the centralization of the Western Australian planning system, it does have clear advantages over that used in other States. One of these advantages is that a consistent approach to rural subdivision policy throughout the State is possible and this prevents land holdings being fragmented purely on the basis of the capacity of a local council to resist pressure. In 1977 a rural study undertaken by the Town Planning Department established the priorities for rural subdivision policy and identified certain resources needing special consideration. Emphasis was given to the importance of the use of Town Planning Schemes throughout rural areas to guide development away from land use conflicts. The policies set down in this Rural Small-holdings Policy Study were adopted by the Town Planning Board as a basis for their overall rural subdivision policy.

Despite the advantages of this Western Australian approach of adopting a comprehensive policy into which local initiatives can develop, there were many detailed matters which were left unresolved in 1977. These matters have been the focus of much of this paper and are now the basis of a study being undertaken within the Town Planning Department. This study will aim to:

1. establish the means by which valuable resources near urban areas may be protected, (the preservation of market gardens, vineyards, mineral resources and the Darling Scarp); and

2. determine the extent to which rural residential subdivision may be permitted in the balance of the rural zone.

The aforementioned study centres upon those areas within commuting distance of Perth for it is these areas most clearly under pressure for subdivision. The study however, will inevitably have implications for the planning of all rural areas affected by subdivision pressure and developing land use conflicts. The major implication will probably lie in the examination and recommendation of techniques which can be used to more perfectly plan rural land in the long term. Certainly subdivision control, as a long term planning technique, will have to be complemented by more positive mechanisms.

Agriculture or Conservation - The Fitzgerald Area

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Abstract

A land use survey of crown land north of Fitzgerald River National Park involved evaluation of agricultural suitability and conservation status. The overlay method highlighted areas of land use conflict.

Most of the plains in the survey area appeared suited to agriculture though some areas were rejected due to isolation. Approximate boundaries were drawn for six farm and five consolidation blocks. A substantial portion of the area was recommended for addition to the National Park.

Introduction

Until comparatively recently little or no consideration was given to conservation when new areas of farming land were opened up for development. Indeed, in many locations only small and inadequate areas were left as reserves. Elsewhere the areas left were obviously unsuited to agriculture e.g. the Stirling Ranges. Since the second World War some attention was paid to soil surveys as a tool in determining agricultural suitability of new land. Current policy has been reviewed by Hogstrom (1979). The government presently favours consolidation to better utilize infrastructure or to expand farm size. Any new land considered for agricultural use must be referred to the Environmental Protection Authority for comment.

Present environmental concern over land release has coincided with decreased demand following the farming recession of 1969. In that sense perhaps we are now adopting a strategy which will ensure the survival of examples of vegetation types and of threatened species of fauna. Similarly development plans must be provided which seek to minimise the environmental hazards consequent to clearing and cultivation (Hogstrom, 1979). Publication of the "Green Book" (Conservation Through Reserves Committee* 1974) drew attention to the status of vacant Crown Land adjoining Fitzgerald River National Park (FRNP).

The present paper reports on a land use survey undertaken by the author in the spring of 1977 (Newbey, unpublished), covering some 64,000 ha of land between the northern boundary of FRNP and existing farmland (Fig. 1).

CTRC (1974) recommended that this area be added to FRNP. The Fitzgerald community approached the Department of Lands and Surveys in 1975 seeking release of suitable areas for farming. The community sought land release to increase district population so as to maintain essential services, and also to increase grain production to the level at which Co-operative Bulk Handling would install grain bins. Mixed farming was envisaged with 2-row barley, oats, sheep and cattle.

The object of my survey was to attempt resolution of the issue in a practical manner by examining the vegetation types for conservation value, and assessing the agricultural potential of the soil resources of the area. It is believed to be the first attempt undertaken in Western Australia to demarcate potential land use in this way.

General Features

The study area is long (75 km) and narrow (≯ 10 km) in shape (Fig. 2) with its southern boundary coinciding approximately with the Stirling Fault, and also the southern margin of the Yilgarn Block (Johnstone *et al* 1973). The main bedrock types are granite/gneiss complex and greenstone/granite complex. Suites of narrow dolerite dykes are common near the fault and tend to decrease northwards. The river valleys have small relict sedimentary Plantagenet Beds (Cockbain, 1968) within 5 km of the Stirling Fault.

The area is an almost flat plain of an ancient landscape (Mulcahy and Bettenay, 1971) which has been dissected by three main river valleys that underwent substantial rejuvenation during the last major Ice Age. Areas with granite/gneiss bedrock are drained by Jacup Type Valleys, and with greenstone/granite by Cowerdup Type Valleys (Newbey, 1979). All major streams are saline.

The plain soils are dominated by deep lateritic profiles which have been truncated into the mottled zone, with a shallow covering dominated by quartz sand. River rejuvenation has affected about half of the study area, including all the Cowerdup Type Valley, to the point where valley soils are less than 1 m thick. In these areas bedrock exposures and skeletal soils are common. Overlying the dolerite dykes are red crumbly clays, usually less than 1 m thick, with rock and stone being common.

The study area's valley types, with their associated soils and vegetation, are poorly represented in the FRNP.

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* Referred to subsequently as CTRC.

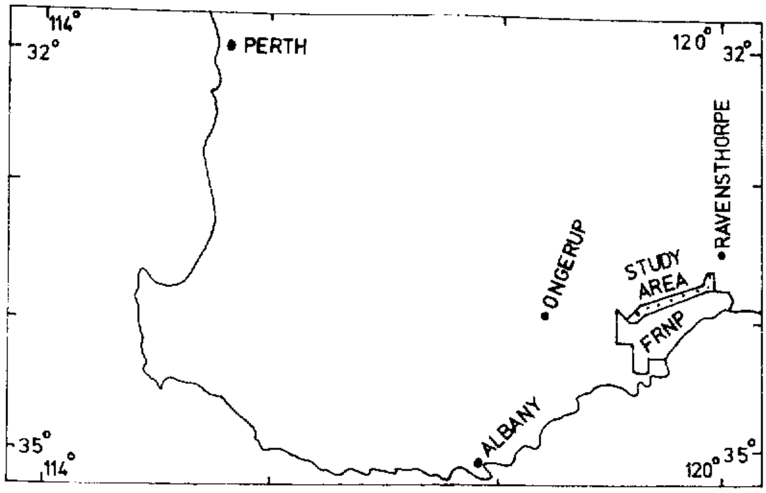

Fig. 1. Location of the Fitzgerald River National Park (FRNP) and the study area.

Methodology

For undeveloped areas much weight has to be placed on comparisons with developed areas. In matching agricultural potential ideally one should have climatic data in addition to vegetation and soil assessments. The climate could only be estimated from a single official rainfall recording station (farmer) on the study area's northern boundary, and his observations of rainfall patterns over the study area. Coastal stations of Hopetoun and Bremer Bay were considered in estimating the possible rate of rainfall increase towards the coast.

My first step was to examine aerial photography of the area at 1:40,000 to determine vegetation and landscape pattern. At this scale the smallest practical unit mappable was 40 m in diameter.

Vegetation Sampling

My study of nearby areas with similar valley types, indicated that the vegetation classification of Specht (1970) based on structure could be the basis for vegetation mapping. His classification is defined from the upper stratum using life form, height range and projected foliage cover. In addition I defined one or two dominant species to name associations or in some cases utilised general features locally characteristic *e.g.* Chenopod low shrubland, Granitic tall open shrubland. Where the vegetation was a complex mosaic with structural changes below the level of practical mapping units I named the association after a major characteristic *e.g.* Spongolite Complex.

Field traverses were used to confirm aerial photographic interpretation, and to elucidate those complex areas which were accessible. From the vegetation mapping typical sites were selected subjectively for each plant association. Plotless sites were used because minimal area had not been established for the plant associations present, and time was limited.

At each site attributes of agricultural constraints and conservation features were recorded. Some attributes were used in both categories. All percentages and heights above 1 m were visual estimates.

Vegetation data recorded were height range and projected canopy cover of each stratum. Canopy cover for the structural classes of Muir (1977) was estimated, to assist Zoologists in determining the study area's habitat range and species expected to be present. The species present in each stratum were listed, and their projected foliage cover estimated for abundance classification (Table 1).

Any additional plant species in other parts of the plant associations were also recorded for a species list.

While sampling the soil, surface conditions were noted as depth and type of litter determines potential habitats for some fauna, as does rock shape, size range, and cover.

A sample site record is illustrated in Appendix 1.

Table 1. Abundance classes for plants.

Abundance class	Very common	Common	Frequent	Scattered	Rare	Very rare
Projected foliage cover %	20	10-20	5-9	1-4	<1, few plants	One or two plants

Wide-ranging plant associations would require more than one site to highlight any geographical variation. Few tracks, large areas of rugged terrain, and limited time restricted recording in most instances to a single site. However, strong correlations were found between vegetation and soils, geology and geomorphology. Providing sufficient areas of each vegetation association were to be conserved we may confidently expect that most of the component fauna species would also be conserved.

Agricultural Potential

A modified US Department of Agriculture (1962 and 1969) classification scheme of geomorphic and soil attributes was devised for assessing the agricultural potential of the study area. The scheme had 5 classes ranging from 0 (no constraint) to 4 (total constraint). The aim was to establish classes for each attribute with a similar degree of constraint. This meant that some attributes lacked one or more classes *e.g.* salinity with only 0 (none) and 4 (salinity present). Attributes and their classes, discussed briefly below, are listed in Appendix 2.

Water erosion is strongly related to the degree of slope. In the study area, slopes of 2^o–5^o require contouring to prevent erosion. Slopes of more than 5^o, breakaways and prominent drainage lines are considered unsuitable for agriculture. Rock outcrops, and stoniness above certain levels, both interfere with cropping but pasture can sometimes be grown on stony soils. Flooding is undesirable for cropped areas and rarely benefits pasture. Closely associated with flooding is the A horizon drainage. Poor drainage will cause tractors and machinery to become bogged during seeding operations. Potential crops of the area, and some pasture plants, do not survive or grow poorly in waterlogged soils. As irrigation is not possible and the country water scheme unlikely to extend into the study area, on-farm water supplies for stock are essential. Soil profile depth, incorporated with A horizon depth, and the water-holding capacity of B and C horizons determine whether dams of sufficient size in impervious soils can be constructed. The run-off potential into the dams is determined by A horizon depth and texture, degree of slope, and slope length. However, roaded catchments and flat-batter dams can provide sufficient catchment in most difficult situations.

Both water and wind erosion are potential hazards of farming some of the study area soils. Water erosion has been discussed in relation to slope, but soil texture and depth are important *e.g.* deep loose sands to loams on steeper slopes have a high erosion potential. The A horizon of some soils is almost pure quartz sand up to 60 cm thick. Careful management is essential to ensure a sufficient crop or pasture coverage throughout the year to prevent wind erosion. To describe and evaluate the soil profile (Appendix 2) a 50 mm hole was augered to 1 m wherever possible. The thickness of deeper profiles was estimated from geomorphology and observations of dams on adjacent farmland.

The next stage was to study those plant associations common to the study area and adjacent farmland, to determine potential crop yields and stocking rates. Much of the new land, released in 1962, was in the early stages of development before the full potential of the land could be ascertained. A successful original farmer, with a large proportion of his land in full production, was approached for crop yields that included averages, highs and years of low returns or failures. Stocking rates for sheep and cattle were investigated on the basis of the stock being run as scavengers without the conservation of grain or fodder.

Evaluation

The overlay method (McHarg, 1969) was used for the evaluation of agricultural constraints and conservation features. Two maps were prepared for this purpose.

Vegetation Map

Shown on this map were vegetation, conservation status of each plant association, and locations of rare or important plants or fauna. Vegetation was mapped at 1:40,000 and conservation status of plant associations was determined as follows:

a) adequate representation in FRNP

b) poorly represented in FRNP

c) not present in FRNP

Some plant associations only occur infrequently in small areas *e.g. Eucalyptus astringens* low open-forest on spongolite breakaways, whilst others are extensive *e.g. Eucalyptus redunca* tall open-shrubland on the plains. Minimal area for long-term survival for each plant association was impossible to define objectively, as too little was known about the ecology of component species. As a guide, the frequency and area range were estimated for those plant associations on similar landscapes in adjoining areas.

Rare and important species of flora and fauna were classified on the basis of their representation in other reserves or National Parks *viz:*

a) adequate

b) poor

c) not represented

Determining minimal population size was not possible because of incomplete knowledge of the species. For plants, as a very general guide, 200 individuals within fertilization distance appeared to be required for annuals or other species reproducing primarily or wholly from seed. For species regenerating by suckering, 20 appeared to be the minimal number.

Agricultural Constraints Map

Displayed on this map were the mappable agricultural constraints: areas with a loose sandy A horizon, areas of rock, and slope categories.

Areas with a loose sand A horizon, clearly visible on aerial photography by their light background colour, were marked "S". These soils had a high wind erosion potential. Rock exposures visible on aerial photography were marked "R".

Slope was mapped in three classes:

a) less than 2° which would not require contouring

b) 2°-5° which would require contouring

c) more than 5°, breakaways and major drainage lines; all unsuited to agriculture

Salinity was confined to the narrow channels and, as most valleys were V-shaped, would only spread a few metres up the slopes. On the non-rocky areas with terrain suitable to agriculture, most component plant associations were the same as those of adjacent farmland.

As a secondary, but still important consideration, the conservation of large areas of the different valley types would help to ensure reasonable representation of the distribution of component plant associations.

Results

The 33 sites sampled in the study area represented 24 plant associations. Their conservation status indicated that 7 were adequately represented in FRNP, 11 were inadequately represented and 6 were not represented.

Yields on adjacent farmland suggested that rainfall would be suitable for 2-row barley and oats. As rainfall increased southwards over the study area, wheat was excluded because of the high rust-risk factor. Sheep were viable but cattle were considered marginal.

The overlay showed that, in general, conservation areas did not clash with areas of agricultural potential. The plant associations with high or moderate conservation value were mainly confined to the valleys. Those with low values occurred mainly on the plains but a few areas of moderate value were also found on the plain. When valley types were considered, all the Cowerdup Type Valley was unsuited to agriculture because of steep terrain, rock and shallow soils. This area also contained a number of plant associations with high conservation value. Slopes and drainage lines of the Jacup Type Valley were well represented but the plains were not.

The next step was to consider rare flora and fauna. Here was the only major area of conflict in the study. The Ground Parrot (*Pezoporus wallicus*) and a rare plant species (*Scirpus sp. nov.* KRN 4857) had been recorded in an area east of Coompertup, which was suited to agriculture but had some small and scattered areas of rock and shallow soils. The Ground Parrot is rare in Western Australia and the few previous sightings were close to the coast *e.g.* Cape Riche (Serventy and Whittel, 1967). It was decided to set aside 730 ha of this area (Area C, Table 2; Fig. 2b) for conservation, possibly as fauna and flora reserve (McKenzie 1973).

At this stage a new land block should be defined. The State Government is under a moral obligation to ensure that blocks made available for agriculture have been proved to be suited for this purpose by detailed land use surveys, and that their best use is agriculture. At least 90% of such blocks should be suited to long-term cropping and pasture *e.g.* not rocky or likely to become saline after clearing. Their size should be at least the anticipated viable area 10 years hence, or be offered as consolidation blocks (Hogstrom, 1979).

Areas suited to agriculture were next examined for area, shape and location. The size of a viable block in the study area, from personal farming experience, was estimated at 1,400 ha in 1977. Consolidation blocks are much smaller with a suggested size range of 100-400 ha. All blocks should join existing farmland because of the high infrastructure cost of isolated blocks, and the vermin problems of being completely surrounded by natural areas. Block shapes need to be practical with regard to surveying, fencing, and farm management. Isolated areas of less than 500 ha were not plotted (Fig. 2b) unless they were adjacent to farmland. Table 2 lists the areas with agricultural potential shown on Fig. 2a with approximate sizes. The eight areas mapped totalled about 15,070 ha, and ranged in size from 500 to 6,800 ha.

Boundaries were drawn on the final land use map to demarcate areas (Fig. 2b) as follows:

a)	to be added to FRNP	25,700 ha
b)	with numerous mining claims	10,690 ha
c)	a reserve under W.A. Wildlife authority	4,780 ha
d)	available for farming	11,130 ha
e)	to remain as Crown Land	11,700 ha

The area with numerous mining claims has a high conservation value, and as much as practicable should be added to FRNP after these claims have been fully evaluated.

The final land use decisions have reduced the area suitable for agriculture from 15,070 ha to 11,130 ha. Isolated areas A and H (Fig. 2a) have been discarded, and C has been allocated to conservation. Most sections within the area to be added to the FRNP have deep sandy A horizons prone to wind erosion. The need for practical boundaries has caused some other small losses. The shapes of those areas best suited to agriculture were poorly

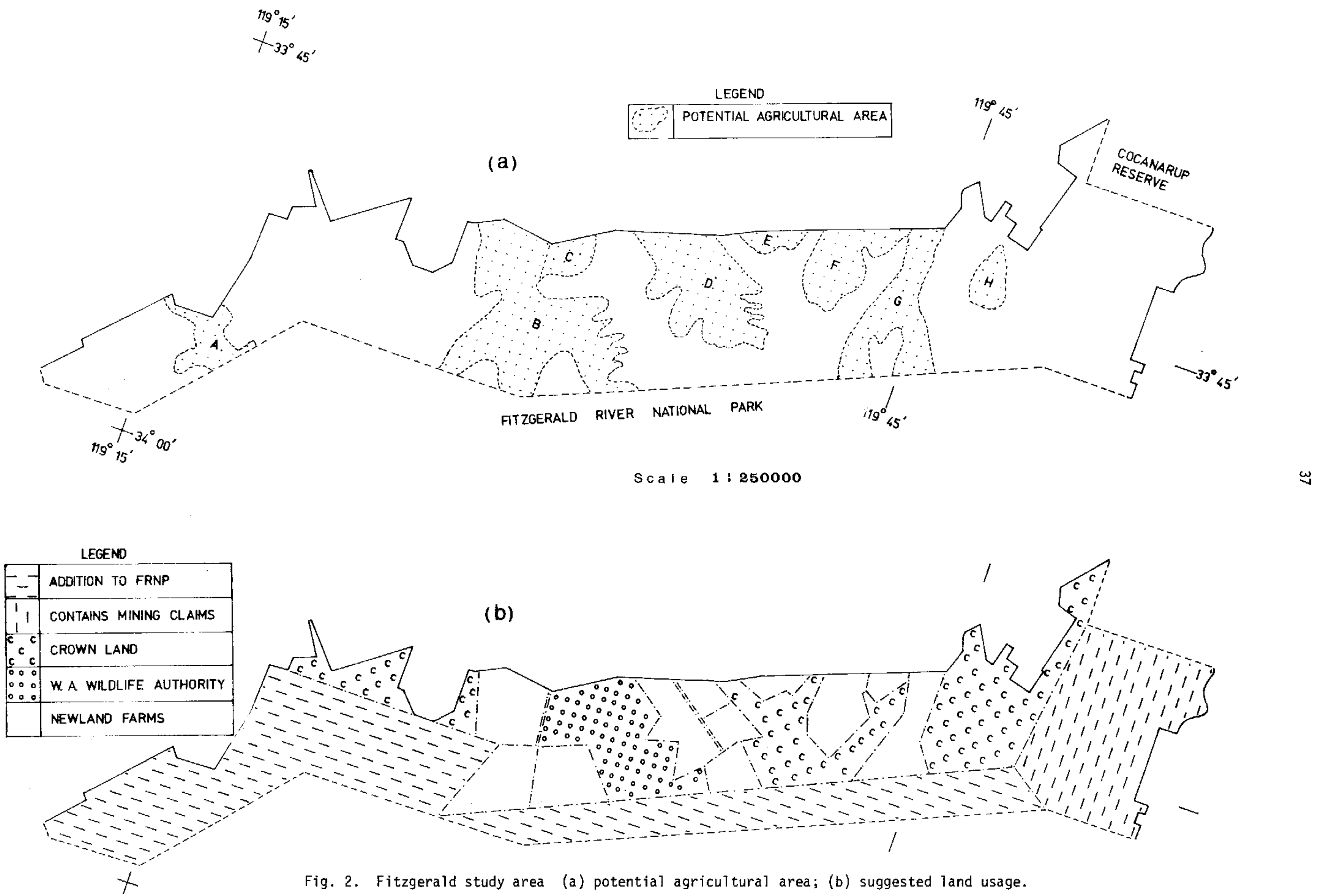

Fig. 2. Fitzgerald study area (a) potential agricultural area; (b) suggested land usage.

Table 2. Areas suited to agriculture and their suggested final land use.

Locality*	Size (ha)	Area in new land blocks (ha)	Comments
A	1070	-	Too isolated.
B	6800	5118	4 farm blocks. Southern sections with sandy A horizon to FRNP.
C	730	-	Conserved - presence of *Pezoporus wallicus* and *Scirpus sp. nov.* KRN 4578.
D	3650	3601	1 farm block and 3 consolidation blocks.
E	500	500	1 consolidation block.
F	2020	2020	1 farm block and 1 consolidation block.
G	2810	1910	1 farm block.
H	900	-	Too isolated.

* See Fig. 2a

suited for surveying into farm blocks. However, 6 farm blocks (1518-1910 ha) and 5 consolidation blocks (300-731 ha) were mapped. Most of the blocks have substantial boundaries with natural areas.

The area set aside for conserving the Ground Parrot was added to a major valley, resulting in a reserve of about 4,780 ha (item C above). The area of FRNP would be increased by about 25,700 ha with only a small increase in boundary length.

Discussion Points

This study highlighted a number of problems even though the case was simply conservation vs. farming. Included below are some potential problems for other areas where similar land use surveys may be undertaken.

1) At present, only a few areas in Western Australia have been surveyed in sufficient detail to provide base data for a similar type of land use survey.

2) Collecting base data for large areas is very time consuming. Defining practical base units, which have strong geomorphic-soil-vegetation correlations, and detailed sampling of selected typical sites, is time-saving.

3) It may be important to attempt to define minimal areas required for the long-term survival of plant associations.

4) Evaluating the agricultural potential for each plant association, or other vegetation unit, is difficult for people with no practical experience of the types of farming possible on these areas.

5) Some areas are suitable for agriculture provided that they are managed carefully *e.g.* steep slopes or loose sands. The question is: should these areas be made available for agriculture? While new land applicants can be screened to some degree, future owners can not. Once wind or water erosion has become extensive, reclamation is costly and often impossible. Prevention of such deterioration on farm-land is paramount.

6) The viable area of new land blocks in this general area, has increased from an estimated 800 ha in 1950, to 1,400 ha in 1977. Much of the higher area requirement is due to increased borrowing, use of larger machinery and demands for higher living standards. What will be the viable block size in 20 year's time when the successful applicants, or their sons, will still be farming these blocks?

7) In this case, the community of Fitzgerald genuinely required more farmland to maintain or attract essential district services. However, this fact was not, and should not be considered in land use decisions. This social attribute is largely dependent on rural politico-economics and varies with location and time.

8) Where farms have a common boundary with National Parks or reserves, there are problems with fire control, and often vermin. Discussion on remedying these problems is outside the scope of this paper but they do need some consideration in land use surveys. A successful applicant should accept these problems as part of the price to be paid for such new land blocks. However, he rightly expects the authorities controlling these areas

to have some fire prevention methods and vermin control.

9) Local farmer involvement is essential in determining yields of grain and stock. As most potential agricultural areas adjoin new land areas, Co-operative Bulk Handling records are not an accurate guide to yields as new land takes 8-10 years of careful management to be brought into full production. However, some care needs to be taken with sources of local information. Farmers, with a vested interest in new land, will often supply exaggerated information if the researcher is obviously inexperienced in the types of farming being discussed.

10) It is paramount that a suitable coverage of unmanned weather stations, for rainfall and evaporation, be established in potential new land areas *e.g.* Lake King-Salmon Gums-Coolgardie-Yellowdine, as soon as possible. This will allow sufficient data to be available if and when these areas are considered for agriculture.

Conclusions

For this study, the vegetation classification of Specht (1970) provided base units which were strongly correlated to geomorphology and soils. The smallest area of 40 m in diameter was of sufficient size to be representative on maps drawn from aerial photography (1:40,000). The aerial photography was adequate for studying plains and most slopes. However, a scale of between 1:20,000 and 1:10,000 would have been useful in areas of fine-textured drainage. Black and white photography was found to be satisfactory for this area. The overlay method was found to be useful in elucidating potential land use conflicts.

The first map displayed vegetation, plant association conservation status and sites of rare plant and fauna sightings. The second map showed agricultural constraints of slope, and areas of rock and sandy A horizon. It was found that most of the plains were suited to agriculture, and the major valleys to conservation. About 15,070 ha were suited to agriculture but in the final analysis this was reduced to 11,130 ha. Reasons for the decrease were: isolated areas, 730 ha set aside for Ground Parrot conservation, and some of the sections with loose sandy A horizon were included in a larger area for adding to the Fitzgerald River National Park. Approximate boundaries were drawn for six farm and five consolidation blocks.

Of the remainder, 10,690 ha included numerous mining claims and could not be classified until these had been evaluated. An area of 25,700 ha was recommended as additions to the Fitzgerald River National Park, with a further 4,780 ha for conservation of the Ground Parrot, perhaps controlled by the W.A. Wildlife Authority, and 11,700 to be left as Crown Land.

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References

Cockbain, A.E. (1968). The stratigraphy of the Plantagenet Group, Western Australia. W. Aust. Geol. Survey. *Ann. Rept.* 1967, 61-63.

Conservation Through Reserves Committee (1974). Conservation Reserves in Western Australia. (Environmental Protection Authority: Perth).

Hogstrom, A. (1979). Criteria applicable in land release/clearing for agriculture. In 'Land Use Planning - Recent Advances'. (Ed. J.R.H. Riches and P.T. Seaman). (University of Western Australia), 60-63.

Johnstone, M.H., Lowry, D.C. and Quilty, P.G. (1973). The geology of southwestern Australia - a review. *J. Proc. Roy. Soc. West. Aust.* 56(1):5-15.

McHarg, I.L. (1969). 'Design with Nature.' (Natural History Press: Garden City, New York).

McKenzie, N.L. (1973). Results of a biological survey of the Shire of Kent, Western Australia. Dept. of Fish. and Fauna *Report No.* 13.

Muir, B.G. (1977). Biological Survey of the Western Australian Wheatbelt. Part 2: Vegetation and habitat of Bendering Reserve. *Rec. West. Aust. Mus.* Suppl. No. 3.

Mulcahy, M.J. and Bettenay, E. (1971). The nature of old landscapes. *Search* 2 (11-12):433-4.

Newbey, K.R. (Unpublished). North Fitzgerald Land Use Survey.

Newbey, K.R. (1979). The vegetation of central south coastal Western Australia. M. Phil. Thesis presented to Murdoch University.

Northcote, K.H. (1971). 'A Factual Key for the Recognition of Australian Soils.' (C.S.I.R.O./Rellim: Glenside, S.A.).

Serventy, D.L. and Whittel, H.M. (1967). 'Birds of Western Australia'. 4th ed. (Lamb Publications: Perth).

Specht, R.L. (1970). Vegetation. In 'The Australian Environment'. (Ed. G.W. Leeper). 4th ed. (Melbourne University Press: Melbourne).

U.S. Dept. of Agriculture (1962). 'Soil Survey Manual'. (U.S. Government Printing Office: Washington D.C.).

U.S. Dept. of Agriculture, Berkeley, California (1969). Land capability classes, subclasses and units. Criteria Sheets 1-16, and Appendices. Duplicated sheets.

APPENDIX 1

Site Description

The description below is a sample of the data recorded at each site and its presentation. For an explanation of Muir Code see Muir (1977). PFC = Projected Foliage Cover. Soil descriptions generally follow Northcote (1971).

Eucalyptus redunca Tall shrubland

Location: 5 km ESE. of Coompertup

Vegetation: Site No. 609 Muir Code: e_1KSi.xSAi.xSCi.Dy4.52

e_1 = *Eucalyptus redunca*

Stratum 1: 2-3 m, PFC 12%

Frequent: *Eucalyptus redunca;*
Scattered: *E. incrassata, E. uncinata;* 2 other spp.

Stratum 2: 0.8-2 m, PFC 2%

4 spp.

Stratum 3: 0-0.8 m, PFC 25%

Scattered: *Andersonia parvifolia, Beaufortia micrantha, Boronia crassifolia, Chorizema nervosum, Coopernookia strophiolata, Leucopogon tamminensis* var. *australiense, Oxylobium tetragonophyllum;* 32 other spp.

Misc. Plants: PFC 1%

Annuals: 3 spp.

Climbers: 1 sp.

Perennial Grasses: 1 sp.

Rosette Plants: 1 sp.

Sedges: 10 spp.

Sedge-like: 1 sp.

Soil No. 14

LANDSCAPE UNIT: Undulating plain

ELEMENT: Traversing all

SOIL PROFILE: Truncated laterite

PRIMARY FORM: Duplex

SOIL ORIGIN: In situ

SOIL SURFACE: Cracking

DRAINAGE PATTERN: Coarse-textured dendritic

SLOPE RANGE: Less than 1° (0)

DEPTH TO BEDROCK: 1-3 m

PARENT ROCK: Quartz gabbro

LITTER: Under mallees broad leaves and twigs 2-4 cm thick, almost continuous.

ROCKINESS: 0%

DISTRIBUTION: - CLASS: (0)

STONINESS: 0%

DISTRIBUTION: - CLASS: (0)

RUN-OFF POTENTIAL: Good (1)

FLOODING: Rare (1)

DRAINAGE: Good

NORTHCOTE: Dy4.52

WATER HOLDING CAPACITY: Unsuited (2)

SOIL FERTILITY: Good (0)

SALINITY: At present: None (0)

AFTER CLEARING: None

EROSION POTENTIAL: Water: Low (1)

WIND: Low (1)

Profile

A 0-7 cm
Greyish brown (10YR4.5/2) sand; sand fraction 15-20% medium and 15-20% coarse subrounded quartz; roots fine and few; less than 2% subrounded gravel 5-12 mm long; less than 2% subangular quartz 2-7 mm long; humus content low; loose; pH 7.0; boundary sharp and wavy.

B_1 7-60 cm
Dull orange (2.5YR7/7) sandy medium clay; less than 5% angular quartz to 3 mm long; very firm; massive; pH 8.0; boundary gradual and even.

B_2 60-100 cm
Pale yellow (2.5Y8/5) medium clay; mottles (a) common, medium or coarse, distinct, clear, white (2.5Y8/2), and (b) few, medium, distinct, clear, red (2.5YR4/6).

SOIL REACTION TREND: Neutral

APPENDIX 2

Agricultural Constraints

The following attributes were recorded in the classes listed, at each site to assist in defining agricultural potential.

Slope

0 - gentle undulating plain with slopes less than 2°.
1 - flat plains.
2 - slopes 2°-5°; contouring required.
4 - slopes greater than 5°, cliffs or breakaways, prominent drainage lines; all unsuited to agriculture.

Rockiness

0 - none seen during field work or from aerial photography.
1 - scattered; tillage possible.
2 - tillage impossible but can be sown to pasture.
3 - natural grazing only.
4 - greater than 50% exposed rock.

Stoniness

0 - none, too few, or too small to interfere

with tillage.
1 - limited interference with tillage.
2 - tillage impossible but can be sown to pasture.
3 - natural grazing only.
4 - greater than 50% cover.

Flooding

0 - never.
1 - occasional, after abnormally heavy rain.
4 - numerous floods expected each year.

Drainage (A horizon)

0 - deep loose soils that drain quickly.
1 - shallow A horizon with good drainage.
3 - soils that drain slowly due to slope and/or micro-relief.
4 - soils that are waterlogged most of the year.

Topsoil (A horizon) Depth

Refers to the A horizon depth but has some relation to the profile.

(a) Soils deep, profile greater than 0.8 m thick.
  0 - A horizon less than 25 cm thick.
  1 - alluvial soils.
  2 - A horizon thicker than 25 cm.

(aa) Soils shallow, less than 0.8 m thick.
  3 - A horizon 0-10 cm thick.
  4 - skeletal soils.

Run-off Potential

0 - clayey soil with more than 1° slope.
1 - shallow sandy loam with slope as above.
2 - soils requiring roaded catchments or flat-batter dams.

Water-holding Capacity

Refers to the ability of B and C horizons to hold water in dams.

0 - good.
2 - unsuited.

Salinity

0 - none.
4 - saline, naturally or after clearing.

Water Erosion

0 - clay A horizon.
1 - shallow loamy sand A horizon.
2 - shallow sand A horizon.
3 - deep loamy sand A horizon.
4 - deep sand A horizon.

Wind Erosion

0 - none.
1 - prevented by average management.
2 - prevented by sound management.
3 - prevented by extremely careful management.
4 - very fragile and unsuited to any form of agriculture.

Fertility (For crops and pasture)

1 - soils require phosphate.
2 - soils require phosphate and trace elements.

Soils

Apart from rock and stone, other soil surface attributes recorded are:

Surface conditions *e.g.* hardsetting and loose.

Pavements: main size range, material and percentage cover.

Litter: narrow or broad leaves, bark, twigs, branches, dead trees; thickness of deposits and average distance apart.

The terminology of soil profile attributes generally follows Northcote (1971). When present, the following are recorded for each horizon: thickness, colour, texture, inclusions, humus, consistence, mottling, pH, and lower boundary.

Agricultural Fertilizer Runoff and Its Potential for Causing Eutrophication of Surface Water Systems

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Abstract

The routes by which fertilizer nitrogen and phosphorous may enter water bodies are discussed. While types of fertilizers and soils may show different rates of loss the increased use of agricultural fertilizers in recent years suggests some cause for concern.

Studies of phosphorous loading in the Peel-Harvey Estuarine System imply that more local research into aspects of agricultural runoff is required.

Introduction

The use of agricultural fertilizers has increased steadily over the past 30 years in both Australia and overseas (*e.g.* Viets, 1971) although usage appears to have levelled off in recent years in Western Australia as is depicted in Fig. 1. Along with the increase in fertilizer use has been a growing concern as to what proportion of farm fertilizers might be ultimately destined for rivers, lakes and estuaries where they could cause excess fertilization of the water. This process, known as eutrophication, generally leads to over-production of algae and other aquatic plants which in addition to being unsightly and foul smelling can cause other ecological problems.

In this paper attention will be focussed on nitrogen (N) and phosphorus (P) as these two elements are mostly in shortest supply relative to plant growth requirements in aquatic ecosystems (Vollenweider 1971), in addition to being the two most widely used fertilizers. In order to appreciate how agricultural fertilizers may enter surface water systems the relevant processes have been summarized in Fig. 2. In this diagram it is seen that fertilizers can enter surface waters as a component of surface and subsurface runoff, and as dustfall from fertilized soils. It is important to note that the nutrients transported in the above mechanisms not only come from fertilizers but also from soil mineral and organic matter, people and animals, which together constitute agricultural runoff and because of the diffuse nature of these inputs it is often difficult to evaluate the fertilizer component (Viets 1971). In order to make this assessment it is necessary to have an understanding of the processes involved and factors affecting nutrient losses via runoff and erosion.

These may be listed as:

The chemical nature of the fertilizers and their reaction with soil

The efficiency of fertilizer use by plants.

The time and manner of fertilizer incorporation into the soil.

The amount of surface runoff and soil erosion.

The amount of leaching and subsurface runoff.

Chemical Nature of Fertilizers and Soil Reaction

Phosphorus is applied as superphosphate double superphosphate or as a component of composite P and N fertilizers. The amount of soluble P in these fertilizers ranges from 7.6 *per cent* to 17.5 *per cent*. Nitrogen fertilizers are applied as urea, ammonium nitrate or as part of composite fertilizers in which soluble N ranges from 12 *per cent* to 46 *per cent*.

There are several important differences in the chemistry of N and P fertilizers which affect the manner and amount by which they may be exported from the catchment and into surface waters.

Phosphorus has the ability to be strongly adsorbed or bound onto clay and organic matter in the soil, or rendered very insoluble by reactions with compounds of iron, aluminium and calcium (Wild 1950). Thus, varying amounts of soluble P will be bound in the soil depending on the amount of clay, organic matter and other minerals present. Previous fertilizer history is also important in terms of how much of the P binding capacity of the soil has already been utilized.

Some important work on the binding capacity of soils has been done by Ozanne *et al* (1961) who found that sandy Western Australian soils with low native P (< 100 ppm) and less than 6 *per cent* organic matter have a poor ability to bind P. The P losses from leaching in the seven soils examined ranged from 17 *per cent* to 81 *per cent* of applied P with the lowest loss recorded from a gravelly soil, and the highest from a grey sand. In soils higher in native P, clay and organic matter losses of P through leaching are generally very low. (Saunders 1959, Walker *et al* 1959). Thus the main mechanism for P loss from agricultural catchments would be through surface runoff except in sandy soils where leaching assumes greater importance.

The ammonium form of N like P can also be bound by soils, thus the concentration of ammonium is not usually high in the soil solution. In contrast the nitrate form is extremely soluble and thus can be readily leached down the soil profile making losses from the catchment by this method potentially much more important. (Biggar and Corey 1969).

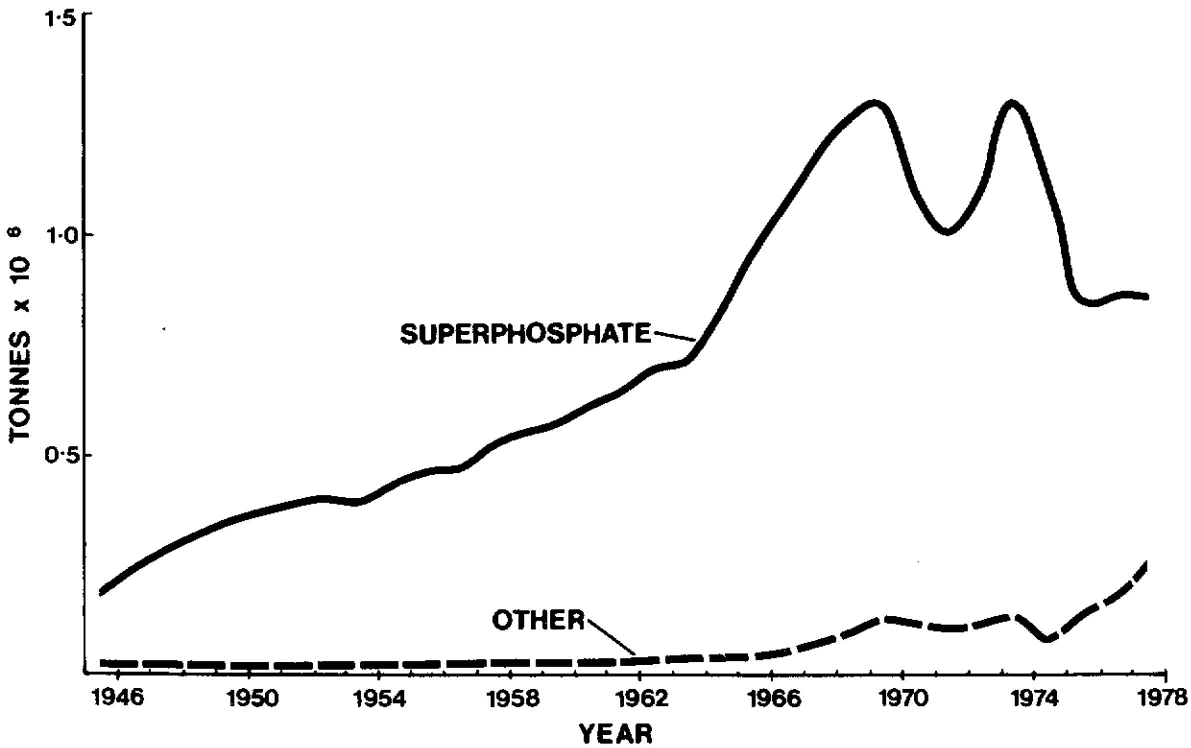

Fig. 1. Farm fertilizer usage in Western Australia over the period 1945/46 to 1977/78. (Data Source: Australian Bureau of Statistics).

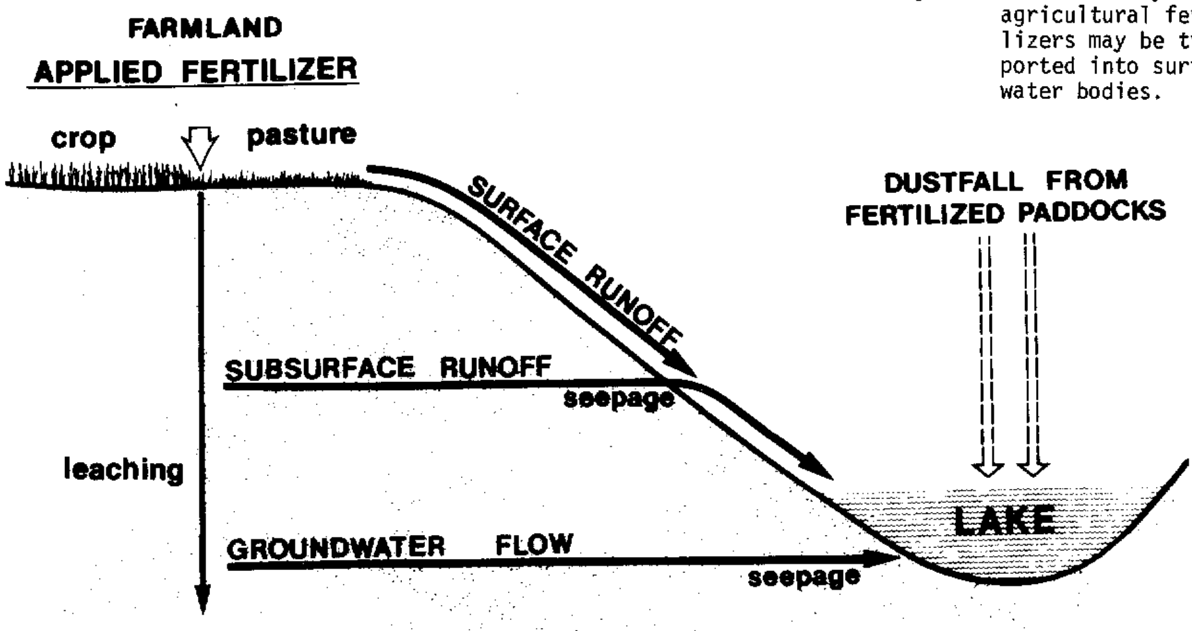

Fig. 2. The routes by which agricultural fertilizers may be transported into surface water bodies.

Efficiency of Fertilizer Use by Plants

The efficiency of fertilizer use by plants depends on the availability of the applied fertilizer to the plant in relation to potential plant growth. It will be appreciated that the fraction of available fertilizer can be quite variable and often quite low due to binding or leaching. As fertilizer is successively added to increase plant yield, efficiency of nutrient use is maintained until maximum yield for the prevailing conditions is attained. If fertilizer is added beyond this point the efficiency of use decreases rapidly thus increasing the amount of fertilizer potentially available for loss via the various mechanisms. This point is clearly demonstrated in Fig. 3 extracted from the work of Fried *et al* (1976).

Incorporation Into the Soil

The timing and manner of fertilizer incorporation into the soil is important because greater loss of fertilizer may occur if application is well before wet seasons (Klausner *et al* 1974). Surface broadcast fertilizer is more subject to loss by surface runoff than is fertilizer incorporated into the soil. For example, Holt *et al* (1970) detected only low concentrations of dissolved P in runoff water from soils having deep incorporation of fertilizers. Similar results were obtained by Römkens *et al* (1973) in their work of relating minimum tillage practices to N and P content in runoff.

Fertilizer Loss by Surface Runoff and Soil Erosion

The amount of surface runoff and soil erosion occurring in agricultural land and its control has been the subject of many studies especially in the U.S. (*e.g.* Wischmeier 1960, Chepil and Woodruff 1963). Surface runoff (or overland flow) occurs when the rainfall rate exceeds its infiltration rate into the soil and as water moves downhill it removes surface soil particles, the amount depending on the velocity of flow, the soil type and its surface coverage. During this process of erosion soil nutrients are lost both by dissolution into the runoff water and in the suspended sediment load. Soil nutrients are also lost in dust by the process of wind erosion but only a fraction of these soil nutrients would be derived from applied fertilizers. For example, in a study of a rural catchment in New York State, Johnson *et al* (1976) determined that less than 1 *per cent* of the P applied to the landscape as chemical fertilizer and manure was lost from the catchment in dissolved form.

In other studies it has been shown that only a small percentage of applied fertilizers (usually less than 1 *per cent*) are lost via surface runoff (Dunigan *et al* 1976, Alberts *et al* 1978). In his discussion on agricultural nutrient losses Vollenweider (1971) suggests that somewhere between 10 and 25 *per cent* of applied N fertilizer (both artificial and natural) finds its way into surface water. No distinction was made between the surface and subsurface mechanisms but in view of the high solubility of nitrate it is reasonable to assume that the major part of the above percentage loss would be through the subsurface route. As far as P is concerned Vollenweider (1971) suggests between 1 and 5 *per cent*, again not distinguishing the mechanisms of loss. In this case surface runoff is probably the dominant route for P loss except in cases where very sandy soils are involved.

Although more studies are needed to evaluate the fertilizer component in surface runoff there are several investigations which demonstrate that increasing the fertilizer rate can increase the amount of nutrient loss in surface runoff. Alberts *et al* (1978) found that nitrate loss doubled and soluble P, sediment N and P losses increased by 13 to 15 *per cent* when very high fertilizer rates were used. Römkens *et al* (1973) showed that more P was lost from fertilized soil because of enrichment by added fertilizer while Römkens and Nelson (1974) demonstrated a linear relationship between P added as fertilizer and soluble P in runoff. They applied superphosphate at the rates of 0, 56 and 113 kg P *per* ha (kg ha^{-1}) and observed resulting concentrations of soluble P of 0.07, 0.24 and 0.44 mg *per* litre (mg l^{-1}) in runoff water. The latter two concentrations are very high in terms of algal growth requirements but the levels of P fertilizer used to produce the concentrations are also very high. Also the final outcome would depend on the quantity of this runoff relative to other sources into receiving waters.

One generalization which can be drawn from the literature on surface agricultural runoff is that most N and P is lost in the particulate form (Alberts *et al* 1978) which highlights the fact that factors which minimise soil erosion will minimise fertilizer losses. According to Wischmeier (1960) soil loss caused by erosion is a function of the climate, soil type, topography and combinations of cropping, management and conservation practices. Thus, except for terracing, it is through cropping, management and conservation practices that soil losses can be minimised. For example, in a study of the effects of tillage methods on the composition of surface runoff, Römkens *et al* (1973) clearly demonstrated that minimum tillage methods reduced fertilizer N and P losses via surface runoff. This was because plots receiving minimum tillage methods had a higher coverage of plant material, less loose soil and greater surface roughness than conventionally tilled plots. Generally similar results are being obtained in studies conducted by B. Marsh of the W.A. Department of Agriculture.

Data on fertilizer loss via wind erosion are very sparse. There is no doubt that dust particles suspended in the air from fertilized fields would contain a proportion of applied fertilizers. These losses could be agronomically significant in certain circumstances. As far as consequences for the eutrophication of water Vollenweider (1971) concludes that aeolian inputs are normally small relative to other sources and only in cases where the water bodies are fed by very nutrient poor waters or are very shallow could atmospheric inputs be important.

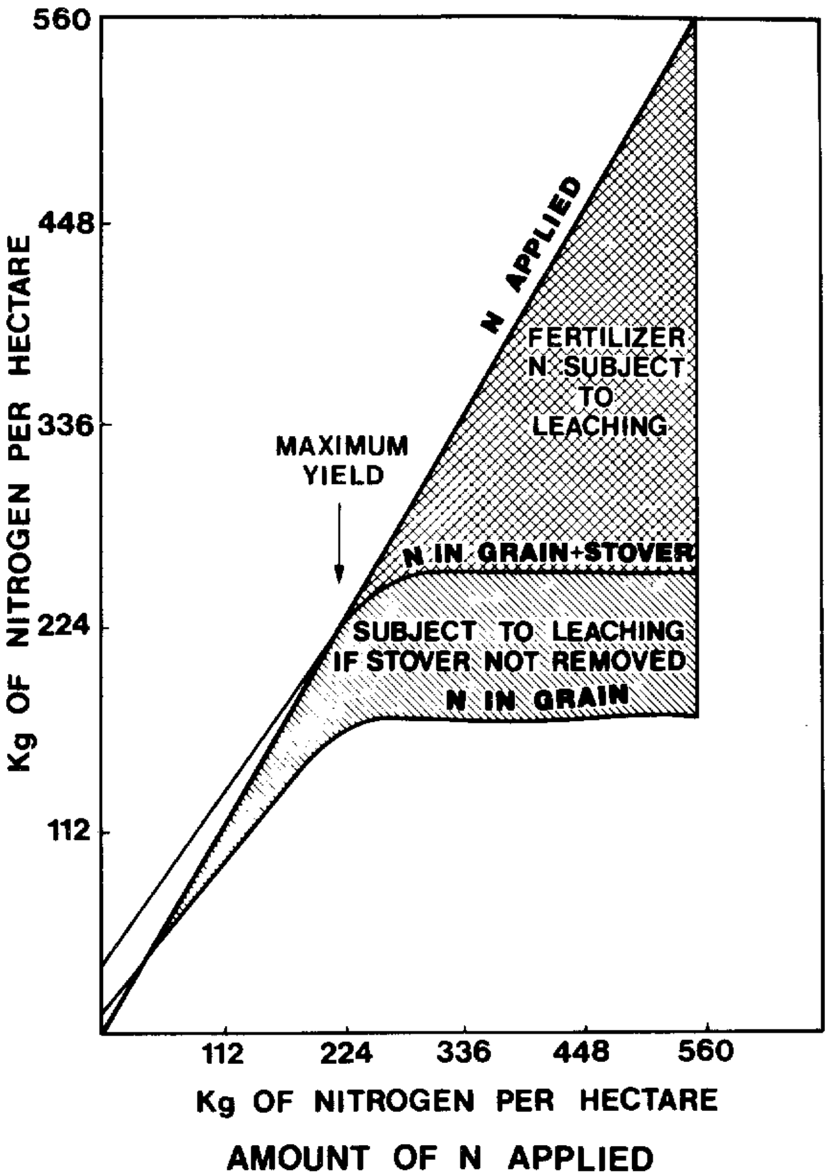

Fig. 3. The effect of amount of N applied on the amount of fertilizer N subject to leaching. (Extracted from Fried *et al* 1976).

Fertilizer Loss by Leaching and Subsurface Runoff

The amount of fertilizer which is not used by plants or bound to the soil is subject to leaching and eventual discharge into surface water by subsurface and groundwater seepage. Of particular importance is the nitrate form of nitrogen because of its solubility. Nitrate losses by leaching are highest in areas of high rainfall and where excessive irrigation and fertilization are practiced (Smith 1967). In a recent study Chichester (1976) found that the N contents of springs draining agricultural land were related to fertilizer N use. Springs draining moderately fertilized cropped land had very high inorganic nitrogen contents of 10-50 mg l^{-1} while a spring draining an unfertilized mixed woodland pasture had low levels of less than 1 mg l^{-1}. In similar work Burwell *et al* (1976) determined that subsurface discharge of nitrate increased from 3 to 5 times when the yearly fertilizer rate was increased from the normal rate of 168 kg ha^{-1} up to 448 kg ha^{-1} *per annum*. These authors concluded that to control the discharge of N and subsequent pollution of streams it was necessary that N fertilization did not exceed crop needs and that conservation practices that minimised soil loss and deep percolation be adopted.

Baker *et al* (1975) conducted measurements for four years of subsurface drainage of phosphate and nitrate from croplands in Iowa. They found that annual discharges were highly variable but the trend was for relatively low average concentrations and discharge rates of phosphate (0.005 mg l^{-1} and 0.003 kg ha^{-1} *per annum*, respectively). The situation for nitrate was quite different. The overall flow weighted average was 21 mg l^{-1} double the U.S. Public Health potable water limit of 10 mg l^{-1}. The average yearly nitrate discharge was 31 kg ha^{-1}. These high results were somewhat surprising in view of the relatively moderate levels of N fertilizer used (224 kg ha^{-1} of N over 5 years). This fact in combination with the large year to year variation left a very unclear picture with the authors as to what was the actual contribution of the fertilizer N. Monitoring of the Skunk River, which drains the agricultural catchment of the study area, indicated some relationship between concentration peaks of nitrate in subsurface drainage and in the river. Even so, no definitive conclusions could be drawn. Nevertheless the results do indicate a potential hazard from subsurface seepage of nitrate into surface waters but a lot more work needs to be done to clarify the picture, particularly the role of fertilizer N. However, in view of the moderate levels of N fertilizer used in this study one suspects that mineralization of soil organic nitrogen into nitrate is playing a substantial role. This effect was clearly demonstrated by Barrow (1969) who studied accumulation of soil organic matter under pasture in a Western Australian sandy soil. He showed build up of soil organic N with time as a result of establishing pasture which had been fertilized with superphosphate. In addition there was substantial buildup of mineral N in the surface 12 cm of soil during spring and summer as organic N was mineralized. In autumn when the first rains came there was a rapid decrease in soil mineral N from about 90 kg ha^{-1} to about 15 kg ha^{-1}. Thus up to 75 kg ha^{-1} of mineral N was removed from surface soil by a combination of surface runoff, leaching and subsurface runoff. The ultimate fate of this N and its impact on the quality of surface water systems in the area is yet to be fully evaluated. Nevertheless this study demonstrates that agricultural pastures in the absence of N fertilizer can result in significant quantities of mineral N in soil potentially available for runoff and enrichment of receiving waters.

It would seem from the literature that subsurface discharge of P is usually relatively small because of the high capacity of most soils to bind P. However, in view of the work of Ozanne *et al* (1961) which showed that up to 80 *per cent* of applied P can be leached from the surface 10 cm of sandy W.A. soils there is a need for studies of water systems draining sandy agricultural catchments to evaluate whether leached P is causing eutrophication. Of equal importance there is a need for further agronomic studies aimed at more efficient utilization of fertilizer P in sandy soils.

Agricultural Fertilizer Runoff in Context

After having reviewed the mechanisms by which fertilizers can be lost from agricultural catchments it is necessary to put these losses in context. In agronomic terms fertilizer losses would generally be insignificant except in sandy soils where leaching is significant or when excessive erosion occurs and research on this aspect is presently underway by B. Marsh of the W.A. Department of Agriculture. From the water quality point of view it has been shown how fertilizer may be exported into surface waters but their eutrophication potential has not yet been clearly established in Western Australia. In Europe and North America some information is available although even here the complexity of agricultural runoff makes assessment difficult. However, a good example comes from the work of Vollenweider (1971) who estimated N and P export values from a hypothetical "representative" catchment in Europe. The catchment has a population density of 150 inhabitants *per* km^2 with 30 *per cent* of the area as cropland upon which the fertilizer application rate is 78 kg N ha^{-1} and 33 kg P ha^{-1}. After suggesting that some 10-25 *per cent* of the fertilizer N and between 1 and 5 *per cent* of the fertilizer P reaches a surface water body the calculated annual export from the catchment due to fertilizer runoff is 2.3-8.0 kg N ha^{-1} and 0.1-0.5 kg P ha^{-1}. For N this is 14-29 *per cent* of the total catchment export; for P it is 6-20 *per cent*. The other sources included wastes of human and animal origin, pastures, detergents, highway, industrial and forest runoff.

The enrichment potential of nutrient export from catchments depends on numerous factors primarily the chemical form (hence availability for plants), the rate of discharge, the type of receiving water body and the ratio of the water body's area to the catchment area. The value of the area ratio must be multiplied by the catchment export to obtain the loading rate into the receiving water. For many lakes the ratio is between 10 and 20. Assuming a ratio of 10 the total annual loading rates for a lake in the hypothetical model calculate out as 170 to 270 kg N ha^{-1} and 17 to 25 kg P ha^{-1} of which the amount attributable to fertilizer runoff is 23-82 kg N ha^{-1} and 1-5 kg P ha^{-1}. The significance of these figures may be deduced from the relationships between loading rate and trophic states of lakes developed by Vollenweider (see Vollenweider 1971, Vollenweider and Dillon 1974). From these relationships one can determine the 'permissible' loading rates for N and P for a lake of known average depth and flushing rate. If the loading rates exceed the 'permissible' rates then the lake is likely to become eutrophic. As an example, the loading figures mentioned above greatly exceed 'permissible' levels for all except very deep (>100 m) well flushed lakes. Even the fertilizer components alone, especially for N, could have a significant enrichment effect on lakes in the average depth range 3 m to 50 m. This is, of course, a hypothetical example for European conditions, although it should be pointed out that Vollenweider's model shows general agreement with actual measurements made in Europe, for example the Lake of Zürich. The situation in Australia, and in particular Western Australia would be different in many respects especially fertilizer application rates which are about one-third of the European figures mentioned above. Other differences include methods of farming, soil types and climate.

An impression of the local scene is obtained from measurements of P loading into the mildly eutrophic Peel-Harvey Estuarine System (Hodgkin and Lenanton 1979, McComb *et al* 1979). The Harvey river and associated agricultural drains which flow into this estuarine system have a catchment area of about 104,000 ha (Black, pers. comm.) upon which it is estimated that approximatley 9,000 tonnes (t) of superphosphate were applied per year in recent years (A.B.S. 1977, 1978, 1979). Using Vollenweider's (1971) suggested fertilizer loss value of 1-5 *per cent* then about 90-450 t of superphosphate or 9-45 t of P would find its way into the estuary from this source each year. In 1977/78, a year of average water flow, the P loading into the estuary was measured as 59 t (Black, pers. comm.). Thus fertilizer P could have contributed from 15 up to 76 *per cent* of the total P input. If the higher figure is anywhere near the mark then fertilizer P is a significant nutrient source for the estuarine system.

The Murray River which also drains into the Peel-Harvey Estuarine System has a catchment area of about 700,000 ha upon which the annual superphosphate application rate of recent years has been approximately 30,000 t (A.B.S. 1977, 1978, 1979). Using the above assumptions an annual loading due to fertilizer P of 30-150 t of P would be discharged by the Murray River. In 1977/78 only 25 t of P were measured to enter the estuary from this source (Black, pers. comm.). Even if the measured load was an underestimate one concludes that even a 1 *per cent* loss rate is too high for at least this catchment. However, unlike the heavier soils of the Murray River catchment (McArthur *et al* 1977) which would be expected to retain P, the generally sandier soils of the Harvey River and drain catchment may not, making the need for further studies on the nature and amount of agricultural runoff very necessary.

Conclusions

1. Agricultural fertilizer use has increased greatly over recent years causing some concern for the eutrophication potential of fertilizer runoff into surface water bodies.

2. Fertilizers can enter surface waters as a component of surface and subsurface runoff and as dustfall from fertilized soils.

3. Nutrients in agricultural runoff come from a variety of sources including fertilizers, soil mineral and organic matter, animal and human wastes. It is generally very difficult to evaluate each component.

4. The amount of fertilizer runoff depends on:

   i) The chemical nature of the fertilizer and its reaction with soil;

   ii) The efficiency of fertilizer use by plants;

   iii) The time and manner of fertilizer incorporation into the soil;

   iv) The amount of surface runoff and soil erosion;

   v) The amount of leaching and subsurface runoff.

5. Research in Europe suggests that a significant contribution to total nutrient export from catchments there could come from fertilizers on the basis of suggested loss rates of 10-25 *per cent* from N and 1-5 *per cent* from P. Applying similar assumptions to the Western Australian situation also indicate possibly significant effects. However, for at least one catchment the loss rate of applied fertilizer P is less than 1 *per cent*. These results indicate the need for more local research into all aspects of agricultural runoff.

References

Alberts, E.E., Schuman, G.E. and Burwell, R.E. (1978). Seasonal runoff losses of nitrogen and phosphorus from Missouri valley loess watersheds. *J. Env. Qual.* 7, 203-208.

Australian Bureau of Statistics, (1977, 1978, 1979). Artificial fertilizer used on rural holdings in Western Australia. Catalogue No. 7403.5.

Baker, J.L., Campbell, K.L., Johnson, H.P. and Hanway, J.J. (1975). Nitrate, phosphorus and sulphate in subsurface drainage water. *J. Env. Qual.* 4, 406-412.

Barrow, N.J. (1969). The accumulation of soil organic matter under pasture and its effect on soil properties. *Aust. J. Exp. Agric. Animal Husb.* 9, 437-444.

Biggar, J.W. and Corey, R.B. (1969). Agricultural drainage and eutrophication. In 'Eutrophication: Causes, consequences, correctives'. Nat. Acad. Sci., 404-445.

Burwell, R.E., Schuman, G.E., Saxton, K.E., and Heineman, H.G. (1976). Nitrogen in subsurface discharge from agricultural watersheds. *J. Env. Qual.* 5, 325-329.

Chepil, W.A. and Woodruff, N.P. (1963). The physics of wind erosion and its control. *Adv. Agron.* 15, 211-302.

Chichester, F.W. (1976). The impact of fertilizer use and crop management on nitrogen content of subsurface water draining from upland agricultural watersheds. *J. Env. Qual.* 5, 413-416.

Dunigan, E.P., Phelan, R.A. and Mondart, C.L., (1976). Surface runoff losses of fertilizer elements. *J. Env. Qual.* 5, 339-342.

Fried, M., Tanji, K.K. and Van De Pol, R.L. (1976). Simplified long term concept for evaluating leaching of nitrogen from agricultural land. *J. Env. Qual.* 5, 197-200.

Hodgkin, E.P. and Lenanton, R.C. (1976). Estuaries and coastal lagoons of south western Australia. In 'Nutrient enrichment in estuaries'. (Ed. B. Nielson and A. Cronin). (Humana Press, New Jersey).

Holt, R.F., Timmons, D.R. and Latterill, J.Y. (1970). Accumulation of phosphates in water. *J. Agr. Food Chem.* 18, 781-784.

Johnson, A.H., Bouldin, D.R., Goyette, E.A. and Hedges, A.M. (1976). Phosphorus loss by stream transport from a rural watershed: Quantities, processes and sources. *J. Env. Qual.* 5, 148-157.

Klausner, S.D., Zwerman, P.J. and Ellis, D.F. (1974). Surface runoff losses of soluble nitrogen and phosphorus under two systems of soil management. *J. Env. Qual.* 3, 42-46.

McArthur, W.M., Churchward, H.M. and Hick, P.T. (1977). Landforms and soils of the Murray River catchment area of Western Australia. *CSIRO Div. Land Res. Management Series* No. 3.

McComb, A.J., Atkins, R.P., Birch, P.B., Gordon, D.M. and Lukatelich, R.J. (1979). Eutrophication in the Peel-Harvey estuarine system, Western Australia. In 'Nutrient enrichment in estuaries'. (Ed B. Nielson and A. Cronin). (Humana Press: New Jersey).

Ozanne, P.G., Kirton, D.J. and Shaw, T.C. (1961). The loss of phosphorus from sandy soils. *Aust. J. Agric. Res.* 12, 409-425.

Römkens, M.J.M., Nelson, D.W. and Mannering, J.V. (1973). Nitrogen and phosphorus composition of surface runoff as affected by tillage method. *J. Env. Qual.* 2, 292-295.

Römkens, M.J.M. and Nelson, D.W. (1974). Phosphorus relationships in runoff from fertilized soils. *J. Env. Qual.* 3, 10-13.

Saunders, W.M.H. (1959). Effect of phosphate topdressing on a soil from andesitic volcanic ash. Part II. *N.Z. Journal Agric. Res.* 2, 445-462.

Smith, G.E. (1967). Fertilizer nutrients in water supplies. In 'Agriculture and the quality of our environment'. (Ed. N.C. Brady). A.A.A.S. *Pub.* 35, 173-186 .

Viets, F.G. (1971). Water quality in relation to farm use of fertilizer. *Bioscience* 21, 460-467.

Vollenweider, R.A. (1971). 'Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication'. (O.E.C.D. Paris).

Vollenweider, R.A. and Dillon, P.J. (1974). 'The application of the phosphorus loading concept to eutrophication research'. National Res. Council Canada No. 13690.

Walker, T.W., Thapa, B.K. and Adams, A.F.R. (1959). Studies on soil organic matter, 3. Accumulation of carbon, nitrogen, sulphur, organic and total phosphorus in improved grassland soils. *Soil Sci.* 87, 135-140.

Wild, A. (1950). The retention of phosphate by soil : a review. *J. Soil Sci.* 1, 221-238.

Wischmeier, W.H. (1960). Cropping - management factor evaluations for a universal soil loss equation. *Soil Sci. Soc. Amer. Proc.* 24, 322-326.

Pesticides Behaviour and Persistence in Agriculture and the Environment

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Abstract

Pesticides consist of a wide variety of chemical compounds and include insecticides, herbicides, fungicides and rodenticides. About 500 tonnes worth over $10 million are used annually in Western Australia on an area of 1.5 million hectares. The behaviour of a pesticide in the environment is complex depending on the physical and chemical properties of the substance and hence persistence, and on the type of environment (soil, water, air) in which it exists.

The use of pesticides is essential to modern agriculture to control pests and maintain high yields. Problems with the use of pesticides are economic and environmental. Economic problems may arise from the development of resistance within the target organism or from trade barriers if pesticides are present at excessive levels in agricultural produce. Effects on the environment include destruction of non-target species and destruction of the habitat of wildlife.

Many of the problems with pesticide usage in the past have involved persistence. Today, because of a better knowledge of pesticide behaviour in the total environment, such difficulties are being overcome and we can hopefully look forward to a future where effects due to pesticide usage will not cause environmental damage.

Introduction

Since the publication of Rachel Carson's 'Silent Spring' in 1963 pesticides have been reported in newspapers as having all types of effects on the environment. We must ask ourselves two questions. What is the real impact of pesticides on our environment? Do we always get a true and balanced view of pesticides? In dealing with the persistence of pesticides a better understanding may be gained and thus help to obtain a balanced view of the environmental effects of pesticides at the present time.

The National Health and Medical Research Council define a pesticide as: '*a substance or compound used or capable of being used or intended for use for agricultural, pastoral, horticultural, domestic or industrial purposes for controlling, destroying or preventing the growth and development of any fungus, virus, insect, mite, mollusc, nematode, plant or animal or for any other related purpose*'. A pesticide residue may be defined as '*a residue in or on a food of any pesticide or any substance that may be derived from a pesticide*'. Thus pesticides include a wide range of chemicals all with differing chemical, physical and biological properties and hence a wide range of persistence and effects on the environment (see Appendices 1 to 5). The persistence of pesticides can range from hours for dibrom to years for organochlorines such as DDT.

Usage

Pesticides are used in all areas of agriculture. In Western Australia the areas treated with pesticides are considerable, being of the order of 1.5 million ha annually, mainly in connection with broadacre farming. Of the 500 tonnes worth $12.5 million used annually in W.A., over 80 *per cent* is used directly by agriculture, the rest being used for public health, building protection against pests, and other industrial uses. Tables 1 and 2 give partial statistics on pesticide usage in W.A.

Table 1. Herbicide and insecticide treatment to cereals and sown pastures.

Year	Area Sprayed ('000 ha)	
	Herbicides	Insecticides
1975-6	1154*	85*
1976-7	1025	78
1977-8	1504	109

* Includes vegetables, orchards, etc.

Source: Bureau of Statistics.

Table 2. Pesticides sold in Western Australia 1978 (Partial list).

Category of Pesticide	Value ($'000)
Insecticides	
Pest Control, Public Health etc.	540
Organochlorines	240
Organophosphorus	960
Carbamates	80
Fungicides (including seed dressings)	1100
Herbicides	
Phenoxy acids	1320
Triazines	230
Substituted ureas/uracils	250
Other	4740
Non Crop	170

Source: Agricultural and Veterinary Chemicals Association

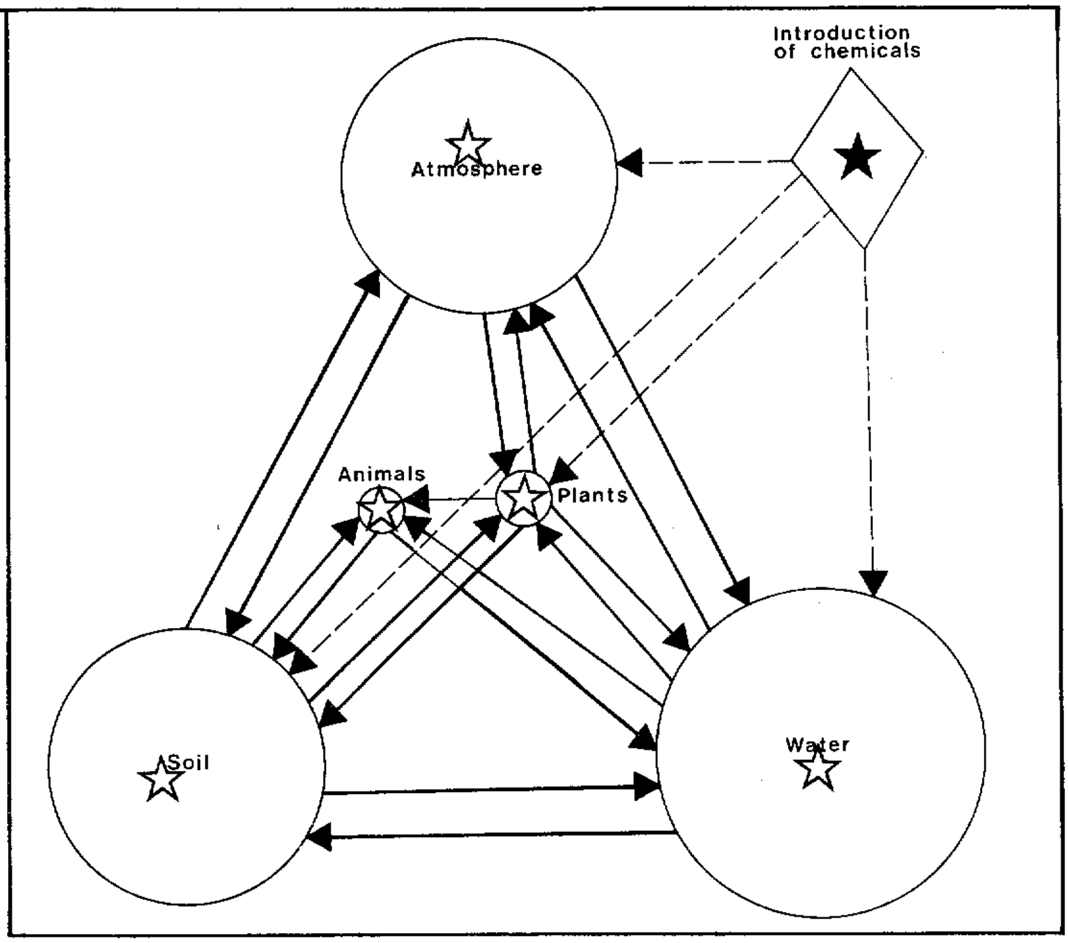


Fig. 1. Environmental phases and the transport of a chemical. (After *Residue Reviews*, 52, p.91).

The major trends in pesticides usage are:

1. the use of less persistent compounds with greater specificity;

2. the phasing out of the more persistent chemicals (DDT, HCB, organomercurials and arsenicals); and

3. the increasing use of fungicides and herbicides.

Behaviour in the Environment

The behaviour of chemicals, including pesticides, in the environment depends on the properties of the chemicals and the characteristics of the environment. Once a chemical is introduced into the environment it becomes distributed between the phases (soil, water, atmosphere, plants, animals) of the environment (refer Fig. 1). Its persistence and ultimate fate in the environment is affected by a wide range of factors including volatility, solubility, ultra-violet irradiation, surface adsorption, hydrolysis, and chemical rearrangement. The weathering actions of light, rain, wind, humidity and temperature play important roles. Once in the soil the effects of soil type, moisture, micro-organisms and cultivation are seen. Pesticides can find their way into both surface and ground water from soil. The persistence of pesticides in air is a function of physical properties, means of application and the atmospheric conditions.

Today not only are pesticide residues monitored in food, but also in the total environment - thus hopefully avoiding some of the pitfalls of the past and whilst improving food production, reduce pollution of the environment. The most troublesome problems have involved chemicals which are persistent, mobile and possess an affinity for fatty materials. These are capable of concentrating in the food chain of aquatic and terrestrial animals. The group of pesticides with these properties is the organochlorine group whose members are being phased out for agricultural use.

There are two ways in dealing in more detail with pesticide behaviour in the environment. These are:

a. to deal with each group of pesticides; and

b. to consider each phase of the environment.

Because of the wide range of pesticides used, the latter approach will be taken.

Table 3. Pesticide properties affecting persistence.

Pesticide Properties	Soil Characters	Environmental Features
Type.	Type.	Temperature.
Volatility.	Structure.	Rainfall, leaching and soil moisture.
Solubility.	Organic content.	Plant cover.
Concentration.	Clay content.	Microbial content of soil.
Formulation.	Mineral Ion content.	Cultivation.
	pH	

Source: Edwards, C.A.; *Residue Reviews* 13, p.83 ff.

Soil

The most persistent pesticides in soil are organochlorine insecticides. The persistence depends on the inter-relationships between:

1. properties of the pesticide;
2. characteristics of the soil; and
3. environmental features as shown in Table 3.

DDT has been shown to have a long persistence in soils heavily treated (up to 50 kg *per* ha over several years) for control of pests in cotton. A slow, although variable, reduction in levels has been recorded as taking place over a three year period after its last use. Leaching was evident to at least 1 m in depth in these soils. Organophosphorus and carbamate insecticides are far more reactive and break down rapidly having a persistence measured in weeks rather than years. Herbicides exhibit a wide range of persistence, ranging from weeks to months. Appendix 4 summarises the persistence over time of individual pesticides in soil.

Some, but not all, herbicides are subject to leaching. Leaching to over 2 m can be seen with picloram where residues are partly bound and trapped near the surface and the remainder are leached out, being present at a depth of 2 m with very little at 1 m. Other compounds such as linuron and diuron are only subject to slight leaching effects. Their persistence in W.A. soils would however appear to be greater than that suggested in the literature for work carried out elsewhere (Appendix 4).

Microbiological activity in soil can play a significant role in degrading pesticides. This has been shown with 2,4-D (*Residue Reviews* 29, pp 192-4) which is used extensively in this State.

Water

Pesticides enter water by runoff, leaching, aerial transport, misapplication, spillage and faulty disposal of wastes. Herbicides are used on channels and channel banks in irrigation areas to control weeds. The contribution made by each process has not been quantified. Nearly all pesticides, except for organochlorines, degrade in water and are deposited and deactivated in sediment. Similar factors to those affecting residues in soil apply to water.

The levels of organochlorine pesticides have been monitored in rivers in this State and whilst DDT and dieldrin are present, the levels are very low and appear to be declining still further. They are usually associated with suspended matter in the water due to their low solubilities (*Residue Reviews* 20).

Groundwater has been monitored in areas with a history of high application of DDT and camphechlor. These compounds have been detected at levels approaching the maximum permissible level for drinking water indicating the effects of leaching of soil.

Air

Pesticides enter the atmosphere either directly or indirectly. Direct entry occurs during application, mainly with aerial spray application. Indirect entry occurs by volatilization from plants and soil after application. Air is a global transport medium and worldwide results of monitoring would suggest that certain residues are ubiquitous. The amounts present are low.

Pesticides occur in air as vapours, aerosols and adsorbed on dust particles. The air may transport pesticides over large distances before depositing them back to the surface as may be shown by the transport of 2,4-D over distances of 20-80 kilometres in Washington State, U.S.A. (refer Robinson and Fox 1978) where damage was caused to grapevines by airborne residues.

Living Receptors

Since pesticides do persist in the environment from weeks to years it is possible for them to be taken up by plants and animals either on the site of application or at a distance. For instance, fish in rivers receiving drainage water from an irrigation area will be exposed to any pesticides in the runoff.

Plants grown on land treated with herbicides the previous season may be affected if the herbicide is persistent enough. Exposure of animals is mainly through food although exposure due to air and water can occur.

Exposure to pesticides can lead to calamitous results if the species exposed is susceptible. An example is the effect seen in Perth on the 'Willy Wagtail' during the argentine ant control programme in the 1950's, using dieldrin. In that period numbers in the metropolitan area were reduced considerably. This was a combination of the indirect effect of the pesticides combined with the growth of urbanization.

General conclusions were made following studies in California between 1963 to 1966 regarding organochlorine pesticides in the environment (American Chemical Society 1978). These were:

1. Residues were common both in wildlife and their environment.

2. Species that depended on wetland or aquatic environments appeared to be more heavily exposed.

3. Exceptions among dryland species are carnivorous forms such as predatory birds at the top of the food chain.

4. Biological concentration plays an important role in the presence of residues.

Significance

Without pesticides it would not be possible to produce food at the current levels of production. Their use has improved yields by eliminating insect pests, fungi and competing species. The most important type of pesticide in agriculture in W.A. is the herbicide group. Fortunately this very diverse group of chemicals is of low persistence with few exceptions. On the basis of experiments in several countries it has been estimated that the control of wild oats in cereals could result in increases in yield of from 3 to 148 *per cent* (Perring and Mellanby 1977).

Apart from these positive effects on levels of agricultural production there are some dangers. These are both economic and environmental. Economic dangers are twofold being:

1. The development of resistance within the target organism as has been seen with insect pests in cotton crops in the Ord River Irrigation Area, and

2. The unacceptability of food produced for consumption either locally or on the export market.

Problems of resistance means either applying higher rates of the same compounds or using alternatives which will be more expensive to use. In both cases the net return to the producer will be decreased. With unacceptability of produce due to residues, export markets may be lost or the consumer may receive higher than the acceptable daily intake of the pesticide concerned. Fortunately this country has had a good record with pesticide residues in food and this good record is getting better. (NH&MRC 83rd Session 1977 p.36).

The significance of the use of pesticides in agriculture on the environment is harder to assess. Certainly there is still a great deal of research yet to be done. Until the introduction of modern methods of analysis capable of detecting very minute quantities of pesticide residues in the 1960's little was known. These modern methods have enabled the gathering of information to pinpoint problem pesticides such as the organochlorines. These have been and are being phased out of use for agriculture, although their use for long term protection of buildings and industrial and public health uses still continues.

Because of the time lag between the introduction of individual pesticides overseas and to this country in the past and the generally lower rates of usage here, many of the problems encountered with effects on the environment have been avoided or have been of lesser significance. This time lag is not the case today as release of a product in W.A. is often within a year of that in other countries. However, requirements for registration are now very stringent and such things as toxicity, persistence and effects on the environment are all considered before registration (Department of Primary Industry 1974). This is not to say that problems with the usage of pesticides will not occur in the future. Hopefully research will continue to pinpoint problem areas.

The Future

Pesticide usage has increased rapidly since the Second World War and may continue to do so in the future. Many of the environmental effects of pesticides are known and those compounds found to be harmful have been withdrawn or their use restricted. Most problems found to date have involved persistence and thus the transport through the environment to non-target organisms.

Ways in which our current usage of pesticides may be modified will include:

The introduction of more specific compounds.

The altering of the use of pesticides to include other methods of control such as biological control.

Introduction of resistant crops.

Alteration in agricultural practices.

Conclusions

It can be seen that pesticides persist in the environment in periods ranging from hours to years. The methods of transport of pesticides in the environment are complex and involved. The longer the period of persistence the greater the area over which these compounds may be transported and the greater the danger of environmental damage taking place. Modern technology has improved our understanding of pesticides and is producing safer and more efficient compounds for use in agriculture. The greatest dangers are in the overuse and misuse of pesticides and all involved in agriculture have a responsibility to follow 'good agricultural practice' to minimize dangers to the environment. A basic overview of the behaviour of pesticides in the environment has been given above and should help those using pesticides to appreciate some of the possible side effects on the environment.

References

Much useful material is contained in *Residue Reviews* produced by Springer-Verlag (New York and Berlin).

American Chemical Society (1978). 'Cleaning our Environment. A Chemical Perspective'. (American Chemical Society Publications: Washington D.C.).

Department of Primary Industry (1974). Requirements for clearance of agricultural chemicals. Document P.B. 179 (Canberra).

Edwards, C.A. (Ed.) (1973). 'Environmental Pollution by Pesticides'. (Plenum Press: New York).

Gould, R.F. (Ed.) (1966). 'Organic Pesticides in the Environment'. (American Chemical Society Publications: Washington D.C.).

Kearney, P.C. and Kaufman, D.D. (Eds.) (1969). 'Degradation of Herbicides'. (Marcel Decker Inc.: New York).

Kearney, P.C., Woolson, E.A., Plimmer, J.R. and Isensee, A.R. (1969). Decontamination of pesticides in soils. *Residue Reviews* 29, 137-149.

Martin, H. and Worthing, C.R. (Eds.) (1977). 'Pesticide Manual', 5th Edn. (British Crop Protection Council).

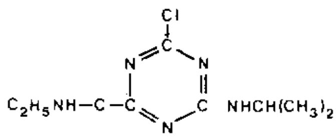
National Health and Medical Research Council (1974 *et seq.*). Annual Reports from 80th Session on. (Aust. Govt. Pub. Serv.: Canberra).

Perring, F.H. and Mellanby, K. (1977). 'Ecological Effects of Pesticides'. (Academic Press: London).

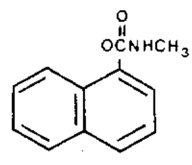
Robinson, E. and Fox, L.L. (1978). 2,4-D Herbicides in central Washington. *J. Air Pollution Control Ass.* 28, 1015-1020.

APPENDIX 1

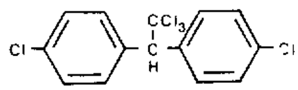
CHEMICAL STRUCTURE OF REPRESENTATIVE PESTICIDES



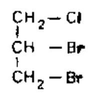
Atrazine



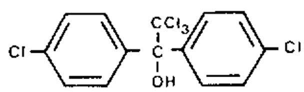
Carbaryl



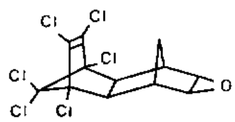
DDT



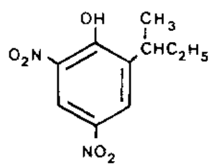
Dibromochloropropane



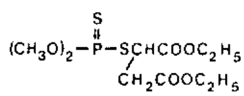
Dicofol



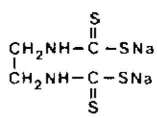
Dieldrin



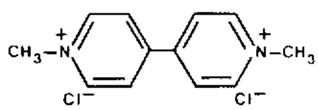
Dinoseb



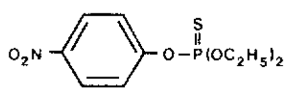
Malathion



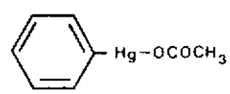
Nabam



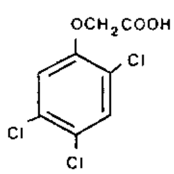
Paraquat



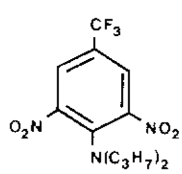
Parathion



Phenylmercuric acetate



2,4,5-T



Trifluralin

APPENDIX 2

PHYSICAL PROPERTIES OF REPRESENTATIVE PESTICIDES

Name	Melting point (°C)	Boiling point (°C)	Vapor pressure torr (°C)	Solubility in water mg *per* l (°C)
Atrazine	173-175		3×10^{-7} (20°)	33 (20°)
Carbaryl	142		>5×10^{-3} (26°)	40 (30°)
DDT	108.5		1.0×10^{-7} (20°)	0.001 (25°)
Dibromochloropropane		196	0.8 (21°)	1000
Dicofol	79	decomp		
Dieldrin	175		7.8×10^{-7} (25°)	0.5 (35°)
Dinoseb	42			50
Malathion		156-157 (0.7 torr)	4×10^{-5} (30°)	145
Nabam	decomp		negligible	3×10^{5}
Paraquat	>300 decomp		negligible	very high
Parathion	6	157-162 (0.6 torr)	3.8×10^{-5} (20°)	24
Phenylmercuric acetate	149-153	sublimes	9×10^{-6} (35°)	438
2,4,5-T	158		<6.46×10^{-6} (25°)	278
Trifluralin	49	96-97 (0.18 torr)	2×10^{-4} (29.5°)	24

Source: American Chemical Society (1978) p.331.

APPENDIX 3

PESTICIDE CLASSIFICATION

Name	Use	Classification
Aldrin	Insecticide	Chlorinated hydrocarbon
Atrazine	Herbicide	Triazine
BHC	Insecticide	Chlorinated hydrocarbon
Carbaryl	Insecticide	Carbamate
Chlordane	Insecticide	Chlorinated hydrocarbon
2,4-D	Herbicide	Phenoxy
DDT	Insecticide	Chlorinated hydrocarbon
Dibromochloro-propane	Nematicide	Halogenated alkane
Dichlorvos	Insecticide	Organophosphate
Dicofol	Acaricide	Chlorinated hydrocarbon
Dieldrin	Insecticide	Chlorinated hydrocarbon
Dinoseb	Herbicide	Phenol
Endrin	Insecticide	Chlorinated hydrocarbon
Heptachlor	Insecticide	Chlorinated hydrocarbon
Malathion	Insecticide	Organophosphate
Methyl bromide	Nematicide (fumigant)	Halogenated alkane
Nabam	Fungicide	Dithiocarbamate
Paraquat	Herbicide	Pyridinium
Parathion	Insecticide	Organophosphate
Pentachloro-phenol	Herbicide, fungicide	Phenol
Phenylmercuric acetate	Herbicide, fungicide	Mercurial
2,4,5-T	Herbicide	Phenoxy
Toxaphene	Insecticide	Chlorinated hydrocarbon
Trifluralin	Herbicide	Dinitroaniline
Zineb	Fungicide	Dithiocarbamate

Source: American Chemical Society (1978) p.326.

APPENDIX 4

PERSISTENCE OF INDIVIDUAL PESTICIDES IN SOILS

a. Organochlorine insecticides	>18 months
Chlordane	5 years
DDT	4 years
BHC, Dieldrin	3 years
Heptachlor, Aldrin, Metabolites	2 years (-3 years)
b. Urea, triazine and picloram herbicides	3-18 months
Propazine, Picloram	18 months
Simazine	12 months
Atrazine, Monuron	10 months
Diuron	8 months
Linuron, Fenuron	4 months
Prometryne	3 months
c. Benzoic acid and amide herbicides	2-12 months
2,3,6-TBA	12 months
Bensulide	10 months
Diphenamide	8 months
Amiben	3 months
CDAA, Dicamba	2 months
d. Phenoxy, toluidine and nitrile herbicides	1-6 months
Trifluralin	6 months
2,4,5-T	5 months
Dichlobenil	4 months
MCPA	3 months
2,4-D	1 month
e. Carbamate and aliphatic acid herbicides	2-12 weeks
TCA	12 weeks
Dalapon, CIPC	8 weeks
CDEC	6 weeks
IPC, EPTC	4 weeks
Barban	2 weeks
f. Phosphate insecticides	1-12 weeks
Diazinon	12 weeks
Di-Syston	4 weeks
Phorate	2 weeks
Malathion, Parathion	1 week

Source: Kearney *et al* 1969.

APPENDIX 5

VAPORIZATION AND LEACHING

Comparative environmental behaviour of pesticides in soil[1]

Compound	Vaporization[2] index (from soil)	Leaching[3] index
Herbicides		
Alachlor	3.0	1.0-2.0
Propanil	2.0	1.0-2.0
Trifluralin	2.0	1.0-2.0
Dalapon-Na	1.0	4.0
MCPA (acid)	1.0	2.0
2,4-D (acid)	1.0	2.0
2,4,5-T (acid)	1.0	2.0
Insecticides		
Carbaryl	3.0-4.0	2.0
Malathion	2.0	2.0-3.0
Naled	4.0	3.0
Dimethoate	2.0	2.0-3.0
Fenthion	2.0	2.0
Diazinon	3.0	2.0
Ethion	1.0-2.0	1.0-2.0
Oxydemeton-methyl	3.0	3.0-4.0
Azinophosmethyl	-	1.0-2.0
Phosphamidon	2.0-3.0	3.0-4.0
Mevinphos	3.0-4.0	3.0-4.0
Methyl parathion	4.0	2.0
Parathion	3.0	2.0
DDT	1.0	1.0
BHC	3.0	1.0
Chlordane	2.0	1.0
Heptachlor	3.0	1.0
Toxaphene	4.0	1.0
Aldrin	1.0	1.0
Dieldrin	1.0	1.0
Endrin	1.0	1.0
Fungicides		
Captan	2.0	1.0
Benomyl	3.0	2.0-3.0
Zineb	1.0	2.0
Maneb	1.0	2.0
Mancozeb	1.0	1.0

1 Estimated from best available information for loam soil at 25°C under annual rainfall of 150 cm.

2 A vaporization index number of 1 = vapor loss of less than 0.1 kg/ha/year, 2 = from 0.2 to 3.0 kg/ha/year or more, 3 = 3.5 to 6.5 kg/ha/year or more, and 4 = 7 to 14 kg/ha/year or more.

3 A leaching index number indicates the approximate number of centimeters moved through the soil profile with an annual rainfall of 150 cm; thus, an index of 1 = <10 cm, 2 = <20 cm, 3 = >35 cm, and 4 = >50 cm.

Source: *Residue Reviews* 52, p.95.

Agriculture and the Environment - Changing Agricultural Techniques

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'Not so many years ago it would have been a madman's dream to suggest that wheat fields and haystacks would now be standing at a place that was once the home of the dingo'.

'The obstacle to rapid settlement is the weight of truly magnificent timber it bears. The trees cleared - and it shocks one to think of sacrificing them even for marketable timber - the soil exposed will be of the very best'.

'How are the trees to be cleared?' 'The trees, even those of considerable dimensions, are readily pulled down by a simple pulley and two horses. The men become experts in a day or two at blowing up the larger trunks with cartridges; and finally the heaped timber is effectively burnt. Very fair wheat and potatoes are growing where red gum flourished a year ago'.

Quotes from 'Western Australia 1925 - an official handbook for the information of commercial men, migrants and tourists'.

Introduction

Agriculture is the largest modifier of the natural environment. Most agriculture, as opposed to rangeland, involves almost complete removal of natural vegetation. Nature strips and shelter belts which are left are sometimes typical of the original upper story vegetation but lower stories are severely modified by grazing and intrusion of exotic grasses and herbs. Roadside reserves are deliberately burnt and aerial sprayers pass over them taking out the more delicate members of the community.

Agriculture, particularly broadscale wheat and sheep farming, makes few concessions to protection of the natural environment. Native fauna in particular is in conflict with agriculture and if it is to be preserved very large national parks are required (Burbidge and Evans 1976, Conservation Through Reserves Committee 1974).

However, while causing greater changes to the natural landscape than anything else man does the results may be more or less aesthetically satisfying depending on ones point of view. Parkland clearing frequently allows trees to grow and spread. The redgum parkland of the Gingin area is typical of this type of clearing. The whole world goes to England to admire the mosaic of hedgerows and stone walls of British agriculture. Agriculture may also open up vistas in what was previously dense bush. These aspects of agriculture versus natural environment have been dealt with by Halse in these proceedings. Other general reviews are those of Ehrlich and Ehrlich (1972), National Estate (1974) and the U.S.A. Yearbooks of Agriculture 1967 and 1971.

This paper will concentrate on the effect of changing agricultural techniques within the already alienated agricultural environment.

Farmers wish to live in balance with their environment. They must exploit the land to produce food and fibre to make a living but they wish also to improve their farms, in an agricultural sense at least, rather than degrade them. Most Australian farms are family owned and may stay in the same family for generations. Farmers are natural conservationists of their agricultural resource because their livelihood, and that of their children, depends upon preserving their farm for the future. However, many of the changes which they inflict upon the landscape may have subtle cumulative effects which in rare cases bring about disaster. They may affect their neighbours, or if in watersheds, communities far removed from their farms. Some local examples of this with salinity are given by Mulcahy and Stoneman elsewhere in these proceedings. Pollution of rivers and lakes in the U.S.A. from nitrogen accumulation from farmland is well documented (Ehrlich and Ehrlich 1972).

Sometimes farmers are victims of economic forces or natural disasters which bring about massive changes to the landscape although generally these can be more or less repaired with careful management. Years of drought and low sheep prices, leading to overstocking, combined with cataclysmic events such as cyclone 'Alby' provide examples of this. Permanent damage to the agricultural environment arises when country goes salty, unstable dunes are cleared or deep gullying of hillsides occurs. This is seldom extensive. Complete degradation of the natural and agricultural environment occurs if the country is abused, but even in these situations management will usually rehabilitate the agricultural environment at least. Much of the so-called 'fertile crescent' of the middle east, home of the Garden of Eden, carried oak forests - today it is denuded range land with not a tree left. But with effort it could be rehabilitated for agriculture. However most changes which the farmer inflicts on the environment are beneficial in an agricultural sense. They bring about increases in productivity without destroying the basic land resource.

In an attempt to illustrate some of the changes which technology brings to the agricultural environment I will trace the major developments which have taken place in the cereal belt of W.A. from clearing to the present day, and with trepidation, likely future changes.

The Natural Environment

The majority of the cereal belt originally consisted of broad, flat valleys with internal drainage along saline flats to salt lakes. The valley floors consisted of clay through to loamy soils supporting Salmon Gum - Gimlet - Morrel open forest. The hillsides and tops consisted of loamy sands and sands frequently over clay or gravel, carrying mallee - tamma - wodgil scrub. Clearing of the more fertile forest soils for agriculture began following the goldrush of the 1890's. These soils had sufficient natural phosphate and nitrogen levels to support wheat crops although they have subsequently been shown to respond further to both (Callaghan and Millington 1956).

The lighter soils were infertile and most of them could not support a wheat crop without the addition of superphosphate and trace elements, and either legume or fertilizer nitrogen. But large scale development of these soils came much later in the 1940's and 50's.

Alienation of land for agriculture is shown in Table 1.

Table 1. Alienation of Land and Area of Crop and Sown Pasture in Western Australia

	Alienated ('000 ha)	Area of Crop ('000 ha)	Area of Sown Pasture ('000 ha)
1829	212		neg
1900	2,679	81	neg
1910	7,013	346	neg
1920	9,317	730	7
1930	14,585	1,938	129
1940	13,127	1,614	477
1950	13,515	1,834	1,435
1960	16,343	2,734	3,074
1970	19,761	3,831	6,588
1975	19,505	4,207	7,447

(ABS Statistical Register and Year Books).

Although many reserves do exist (Muir 1976) the natural environment of most of the wheatbelt has been destroyed but large tracts of almost untouched country highly suitable for agriculture still exist east of the rabbit proof fence in the Hyden - Lake King region (Gartrell, in press). This area is worth a visit and the question of whether or not to develop it is central to the theme of this conference.

The Use of Fertilizers

Superphosphate

Next to clearing itself, application of superphosphate across all agricultural land in Western Australia probably represents the next largest modification to the environment by man. The growth in the use of superphosphate is shown in Table 2.

Initially large doses of phosphate are required, particularly on gravelly light land, to achieve maximum yields of crop and pasture. As residual phosphate builds up lower dressings are applied until finally a low maintenance level is reached. Eventually all agricultural land should arrive at this point. These mechanisms have been described by Bowden and Bennett (1974). The impact of phosphate on agricultural production is enormous. In the most extreme situations no yield at all is achieved without superphosphate.

Table 2. Use of Superphosphate in Western Australia (tonnes)

1900	neg
1910	33,000
1920	66,600
1930	236,000
1940	270,000
1950	359,000
1960	600,000
1970	1,120,000
1975	846,000

(ABS Yearbooks).

Many millions of tonnes of superphosphate have been applied over the years and this massive improvement in the agricultural environment has been wrought by the almost complete destruction of Nauru and Christmas Islands, a resource which will in time be exhausted completely. There is a trend now towards fertilizers with higher phosphate concentrations than superphosphate and towards N-P compound fertilizers. This trend will continue with some effects on the agricultural environment which will be mentioned later.

Trace Elements

Early attempts to crop lighter soil types were often disastrous and utilization was not possible until the requirements for the trace elements copper, zinc and molybdenum were recognized, during the 1940's (Burvill 1971). Following an initial application of these elements further application is not required for many years (Gartrell 1979). Most of the light land which has been treated has shown dramatic effects on the agricultural productivity of these soils. This is an example of a cheap, once only, application of technology having a long term beneficial effect on the agricultural environment. As new fertilizers are introduced into cropping systems, care must be taken that trace element requirements are met. For example, marginal zinc deficiency has appeared in some cases recently when Di-ammonium phosphate has replaced superphosphate which contained small amounts of zinc.

Nitrogen

Nitrogen fertilizer use in Western Australia was reviewed by Roberts *et al* (1966). The general use of fertilizer nitrogen on cereal crops did not commence until 1960. Since then its use has grown rapidly with an annual use now of about 40,000 tonnes of nitrogen. In recent years there has been a swing toward N-P compound fertilizers.

The general use of nitrogen fertilizers is unlikely to have serious effects on the agricultural environment except in one very important area. The use of acidifying nitrogen fertilizers is increasing rapidly at present. The continued use of these fertilizers will lower soil pH on many soils causing nutritional problems (Mason 1975). These fertilizers do have an important side benefit of reducing the amount of the fungal root rot disease 'take-all' (McNish 1977). This is an excellent example of credits and debits accrueing to a single manipulation within the agricultural environment which can have important far reaching implications. It is an obvious area for research.

Legume Pastures

'The three-year rotation is the ideal set for the farmer - first year crop, second year sheep, third year fallow. Eventually this will become the accepted practice, though the general rule in all new districts at present is alternation of crop and fallow'. (Western Australia, 1925).

It was not until 1934 that Dunne and Shier demonstrated the value of legume pastures in crop rotations in Western Australia. Since then the area sown has rapidly increased as shown in Table 1.

The widespread sowing of Dwalganup and later maturing strains of subclover in the 40's and 50's and the subsequent release of Geraldton subclover in 1959, and Cyprus barrel medic in 1961, coupled with superphosphate and trace elements established the agricultural environment of the period 1950-1970. A highly stable agriculture based generally on a one year crop, two year legume, pasture arose.

While enormous benefits accrued from the use of improved pastures this change in technology has also brought its share of problems. Examples of these are the sheep infertility problems attached to the use of high oestrogen subclovers Dwalganup and Dinninup (Bennetts, Underwood and Shier 1946). So successful are these clovers that they are very difficult to replace and in many places appear to have become a permanent part of the agricultural environment with continuing effect on sheep fertility. The introduction of annual ryegrass, while having large grazing benefits, has brought with it the worst weed problem of cereal crops in Western Australia, and ryegrass toxicity of sheep in the Great Southern region. It is often very difficult to assess at the outset the future problems the imposition a particular piece of technology will have upon the environment.

Tillage, Machinery, Herbicides and Cropping Intensity

'We have made enquiry from every source at our disposal and report that no tractor yet introduced into Australia is altogether suitable for Australian requirements and none of the types which have been tried will enable the farmer to dispense with his horse'. (1917 Royal Commission into Agriculture in W.A.).

From the 1890's-1930's the horse and mouldboard plough dominated W.A. agriculture. To grow enough crop to make a living the farmer spent nearly the whole year fallowing or seeding in a wheat-fallow rotation. This gradually gave way to the tractor and disc plough or scarifier and legume ley-crop rotations, which changed very little until the 1970's. Wheat quotas, low sheep prices, inflation, drought and many other forces local and worldwide have brought a technological revolution in tillage and cropping techniques in the 1970's, which will have far reaching effects on the agricultural environment.

Economic forces have pushed fewer and fewer farmers towards growing more and more crop. Table 3 shows this trend in two typical wheatbelt shires. Technology here is affecting the social environment of many wheatbelt towns. In much of the wheatbelt 50 *per cent* or more of the farm is in crop. At the wetter edge of the cropping areas, crop is pushing into areas previously used almost solely for grazing.

A major revolution in tillage practices is taking place. On the one hand in the past 3 or 4 years the 90HP tractor pulling a 22 disc plough or a 24 run combine has given way to the "maxi" 300HP 4WD tractor pulling matched gear-wideline cultivators, triple hitch combines and airseeders. On the other hand we have seen the development of minimum or zero tillage techniques where the soil receives minimal cultivation and weeds are controlled with herbicides (Table 4).

Coupled with these has been a massive increase in the use of herbicides in cropping with obvious environmental implications (Table 5 and Table 6).

Table 3. Area of farm, number of farmers and percent farm in crop in typical wheatbelt shires.

	Kellerberrin				Merredin			
	1954	1964	1974	1979	1954	1964	1974	1978
No. of farmers	210	175	150	140	250	235	200	190
Area of farm ('000 ha)	900	1,100	1,300	1,500	1,000	1,200	1,500	1,650
Per cent farm in crop	32	40	43	55	32	40	45	60

Table 4. Use of spray-seed (Paraquat/diquat) in minimum tillage systems (ha).

1971	10,000
1972	11,000
1973	28,000
1974	70,000
1975	22,000
1976	22,000
1977	25,000
1978	40,000
1979	100,000

(R. Crook, pers. comm.).

Table 5. Use of some new herbicides in W.A. cereal cropping (ha treated).

Year	Trifluralin	Hoegrass	Diuron/MCPA/24D
1973	Exptl.		
1974	4,000		
1975	11,500		
1976	108,000		
1977	370,000	Exptl.	Exptl.
1978	466,000	12,000	430,000
1979	749,000	192,000	780,000

Approximately 1,000,000 ha sprayed with 24D each year. (G.A. Pearce, Pers. comm.).

These changes in technology will have good and bad effects upon the agricultural environment. The use of trifluralins allows less tillage but their incorporation requires preparation of a very fine seedbed prone to wind and water erosion. Minimum tillage practices give protection of the soil surface and lead to a build-up of soil structure and soil flora and fauna - beneficial effects. But they involve continued use of a range of chemicals which although apparently safe, may in the long run lead to detrimental effects on environment. The literature is littered with examples of apparently safe chemicals later being discarded for environmental reasons.

The use of these efficient cultivation techniques combined with chemicals in many cases is leading to much lower weed burdens being carried over from one crop to the next.

Although this is highly beneficial to the crop, leading eventually to a complete lack of weeds, sheep are left with nothing to eat in the years between the crop. Where will the future balance lie? Are we moving towards continuous crop, no sheep agriculture over much of our traditionally wheat and sheep areas? What are the environmental implications of this? Will the shift from the highly stable crop-pasture rotation to crop monoculture eventually invite disaster? Farmers view with great concern the increase in percentage cropped area. They are holding back from 100 *per cent* crop which technologically they could handle immediately. But economic forces drive them towards it.

Will other options or political or economic forces take over? Is continuous crop involving grain legume-cereal crop rotations the best

Table 6. Estimated areas treated with various herbicides for the control of weeds in cereals in 1978 and 1979. (Pearce 1979).

Weed Problem	Herbicide	Area treated - ha	
		1978	1979
Annual Ryegrass	Pre-emergence	496,000	749,000
	Post-emergence	12,000	192,000
Wild Oats	Pre & Post emergence	64,300	110,000
Broadleaved Weeds	2,4-D	1,016,000	1,155,000
Broadleaved Weeds	Dicamba plus MCPA or 2,4-D	224,000	176,000
Broadleaved Weeds	Dicamba	98,600	77,000
Broadleaved Weeds	Diuron (plus MCPA) 2,4-D	43,300	780,000
Broadleaved Weeds	Sprayed 3-5 leaves	132,000	59,000
TOTAL		2,086,200	3,298,700

option? The lupin-wheat rotations look to have great promise in the northern wheatbelt. Will energy eventually become the dominant factor in shaping farming practices?

The technological changes which are taking place in agriculture now are moving faster and are opening up more options than our agriculture has experienced for decades. Is this rapid rate of change a danger in itself in not giving us time to assess the effects of these practices on environment?

References

Bennetts, H.W., Underwood, E.J. and Shier, F.L. (1946). A specific breeding problem of sheep on subterranean clover pastures in Western Australia. *Aust. Vet. J.* 22, 2.

Bowden, J.W. and Bennett, D. (1974). The Decide model for predicting superphosphate requirements. Proceedings of Phosphorus in Agriculture.

Brodie-Hall, L. (1971). A report on proposals for environmental studies into some aspects of natural resource utilization in south Western Australia.

Burbidge, A.A. and Evans, T. (1976). The management of nature reserves in Western Australia. Dept. of Fisheries and Wild-life, W.A. *Report No.* 23.

Burvill, G.H. (1971). Agriculture in Western Australia. *J. Aust. Inst. Agric. Sci.* 37, 89.

Callaghan, A.R. and Millington, A.J. (1956). The Wheat Industry in Australia. (Angus & Robertson: Sydney).

Conservation Through Reserves Committee (1974). Conservation reserves in Western Australia. (Environmental Protection Authority: Perth).

Dunne, T.C. and Shier, F.L. (1934). A modified rotation for the wheatbelt. *Journ. Dept. Agric. West. Aust.* 11 (series 2), 254.

Ehrlich, P.R. and Ehrlich, A.H. (1972). 'Population, Resources, Environment - Issues in Human Ecology.' (W.H. Freeman & Co., San Francisco).

Gartrell (in press). Conclusions on W.A. Dept. of Agriculture investigations into the agricultural potential of the Forrestonia-South Johnson Lakes area (1960-1970). W.A. Dept. of Agric. pubn.

Gartrell, J.W. (1979). Proceedings of a seminar on mineral requirements of sheep and cattle - copper. Aust. Soc. Animal Prod. (W.A. Branch).

Mason, M.G. and Toms, W.J. (1975). Effect of successive cropping with nitrogenous fertilizers on wheat yields. *Aust. J. Exp. Agric. An. Husb.* 15, 823.

MacNish, G. (1977). Annual Report, Plant Research Division, Dept. of Agriculture, Western Australia.

Muir, B.G. (1976, 1977). A biological survey of the Western Australian wheatbelt. *Rec. West. Aust. Mus.* 1-7.

National Estate (1974). 'Report of the National Estate'. (Aust. Govt. Publishing Service: Canberra).

Pearce, G.A. (1979). Proceedings Western Australian Weed Conference 1979. Weed Society of Western Australia.

Roberts, F.J. *et al* (1966). First Report of the Australian Institutes of Agricultural Science (W.A. Branch). Standing Sub-committee on Nitrogen.

U.S.A. Yearbook of Agriculture 1967. U.S. Govt. Printing Office.

U.S.A. Yearbook of Agriculture 1971. U.S. Govt. Printing Office.

"COMMUNICATIONS"

Research on Agro-Forestry

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Introduction

On world standards the efficiency of Western Australian production of food and fibre is very satisfactory. But when agricultural development includes the extensive and almost total removal of trees then landscapes are created which must be very intelligently managed or they may deteriorate. Loss of quality can be through lowered soil fertility and stability, erosion by wind or water, disappearance of native fauna and flora, or through development of salinity. Such cleared landscapes shed water readily but this may have levels of dissolved salts which render it unacceptable for catchment.

Much of our natural forest has been badly over-cut (and it regenerates slowly), parts of it are threatened by disease, and its overall productivity is generally low because of the infertile soils it grows in. In Western Australia, outflow of high quality water ranges from moderate in the western slopes to almost nil further east. Native fauna are abundant though little seen by many. Plantations of pine, though economically viable, are generally considered to be aesthetically unattractive and require the continued exercise of stringent and expensive fire control methods throughout the rotation.

Role of Agro-Forestry

Agro-forestry is a land use offering many possibilities between the above extremes. Suitably fertilized pastures which have a reasonable clover content will maintain the fertility of the soils while widely spaced trees can control erosion by reducing the velocities of winds and water, and help to maintain soil stability by their constant additions to soil organic matter from leaf and litter fall. The trees may provide a habitat sufficiently attractive to entice back the native fauna, particularly the birds and small marsupials. Livestock not only return some income while the trees reach marketable size but also break down litter and maintain low fuel where fire control costs are much reduced. In the western landscapes pines grow well and are the preferred species because they will provide a much needed source of timber in the medium and long term. In these areas the development of agro-forestry (and the tree stocking rates used) could be used to balance the needs of the region for water, timber, meat and wool. Further east, agro-forestry with eucalypts could become a valuable technique allowing the management or rehabilitation of marginal saline areas and crop or pasture production to proceed simultaneously.

Recent Progress in Agro-Forestry

In a collaborative research program, the LRM Division of CSIRO and the Forests Department of W.A. have set up large scale experiments to evaluate sheep grazing and softwood production at various tree stocking rates and at two phases of the pine rotation.

The length of a pine rotation (25-30 years) prohibits its complete study. We have chosen the rapidly changing development phase (the first ten years) and a more stable phase following considerable thinning and pruning (15-20 years) for studies of pasture and live-stock production and their interactions with tree form and growth.

The first experiment follows preliminary studies which developed methods for establishing clover under 13 year old pines and which showed that reasonable production and persistence could be expected under such conditions.

Experiment 1

This has Seaton Park clover sown under 15 year old *Pinus radiata* at 70, 120 and 150 stems ha^{-1}, *P. pinaster* at 90 stems ha^{-1} and control areas from which the pines were clear-felled and removed. The trees have been pruned to 6 m.

Fences have been erected so that treatments can be individually grazed by sheep each year at rates that will fully utilize the pasture by early summer. Liveweight changes and wool growth of the sheep are being measured. Trees are being measured annually for growth rates, and at three yearly intervals for changes in form and nutrient uptakes. Dendrometers are used to monitor seasonal growth patterns.

Other areas were also thinned and pruned but left without pasture. Half of these areas have been fertilized with superphosphate at the same rates as the pasture plots. This allows assessments to be made of thinning alone, thinning + fertilizing, and thinning + fertilizing + grazing of pastures, on tree growth rates *etc.*

About 5 plants dm^{-2} were established from the initial sowing in June 1977 and these made satisfactory growth considering the low rain-fall in that season. Yields of clover herbage ranged from 2500-4500 kg ha^{-1} and seed yields were high on the *P. radiata* plots. On the drier and less fertile soils of the *P. pinaster* site herbage yields were only 1200-1500 kg ha^{-1} and seed yields were also reduced. The *P. radiata* pastures were grazed down to about the level of the *P. pinaster* pastures after the end of the growing season.

In 1978 the pastures regenerated well producing 800-1400 kg ha^{-1} by the end of June, sufficient to allow sheep grazing to commence. Our aim of maintaining similar grazing pressure (hence also similar liveweights) on all plots was achieved by adjusting sheep numbers per plot to pasture availability as estimated periodically. The mean liveweights of the sheep increased from 39 kg in June to 53 kg in December. By January most flocks were losing weight and there was only around 500 kg ha^{-1} of herbage left, so the sheep were removed. From the number of sheep days of grazing per treatment we calculated the approximate carrying capacities, for the whole year, to be 10, 9, 7 and 6 sheep ha^{-1} on the *P. radiata* (0, 70, 120 and 150 trees ha^{-1} respectively) and 7 and 6 sheep ha^{-1} on the 0 and 90 trees ha^{-1} treatments of *P. pinaster*.

The sheep grazing part of this experiment will continue for a few years and the tree growth measurements somewhat longer. From the carrying capacities of the pastures and the estimated timber yields it will be possible to make economic comparisons of the pine and pasture combinations used. The combination of high pruning and heavy winter and spring grazing creates a very low fire risk situation by December, requiring no other fire control than maintenance of fire breaks.

Experiment 2

This required the planting of 24 ha of pines and 3 ha of eucalypts on old pasture land and this was completed in July 1978. The design of this experiment allows several objectives to be met. The first is to compare the effects of planting density (0, 380, 760, or 1140 trees ha^{-1}) of *P. radiata* on tree growth rate and form, and on pasture production. The second compares the effects of *P. radiata*, *P. pinaster* and *Eucalyptus camaldulensis* each at 760 trees ha^{-1} on pasture growth and composition. The third will measure the effects on tree growth and pasture production of varying row spacings, planting pattern, time and severity of pruning and methods of treating trash, all with *P. radiata* planted at 760 trees ha^{-1}. The pastures will not be grazed until 1980 so that damage to the trees by livestock can be avoided. Twelve piezometric wells have been drilled to bedrock so that changes in groundwater and salt levels may be monitored as the trees developed. A further twelve shallow wells monitor perched groundwater tables. No results are available at this stage.

Trees and Salinity

Where part or all of the landscape is used for farming, development of soil salinity can occur and the yield and quality of water reaching streams and dams is affected. We are investigating land management systems that will allow agriculture to continue but which will have less harmful effects on soil and water salinity. Central to this work is revegetation of parts of catchments with trees to act as water pumps and so change the hydrologic balance back towards that occurring before trees were cleared.

Experiments in the Hotham and Helena valleys and at Bakers Hill are investigating which tree species are suitable both agronomically and hydrologically. The effects of planting different proportions of the landscape to trees is being examined, and management of land in young tree plantations is being studied with the aim of minimising losses in agricultural production.

Blocks of 100 trees of *E. wandoo* were planted in old pasture land in 1977, to compare the effects of landscape position and size of tree blocks on the composition and productivity of pastures downslope.

Blocks of *E. wandoo*, *E. camaldulensis*, *P. radiata* and *P. pinaster* were also planted in lower slope positions to compare the effect of species. In each tree block one shallow and one piezometric well has been installed so that groundwater level and salinity changes can be monitored. The trees have established and are growing well but changes in water levels and productivity have not yet occurred.

Private Rural Reserves

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Introduction

Probably the most important step in setting aside a reserve for the preservation of wildlife is to isolate the area before clearing or burning takes place. This retains the ecological balance of food, cover from predators and natural breeding sites. Consideration should be given to the inclusion of tall trees, dense scrub, waterways, hills and rocks where possible. By far the most important factor is that they be fenced off from livestock.

Function

Land treated in this manner can serve two other important purposes. The first is to give a windbreak and protection to livestock. Secondly, such timbered areas help restrict the rise of the saline water table and also reduce runoff that may deposit salt on the lower levels.

The practice of bulldozing an entire area then putting a fire through and allowing regrowth on the rough hills is not recommended as grazing stock allow only a few trees to survive and few, if any of the wildflowers. Furthermore, nesting sites and food are gone and birds leave the area, also the small mammals are unable to escape the fire.

Granite or laterite hills previously timbered with wandoo, York gum or jam and reduced only to a few trees because of fire and natural death may be regenerated by fencing off for a period of, say, three or four years. This will allow seeds to germinate and enable the young trees to get beyond the reach of sheep. This process will be assisted if old logs or debris are burnt during the autumn. This has the effect of heat-treating the dormant seeds and providing a sterilised seed bed for the young plants. In the case of an excessive regrowth, the timber may be thinned and used for fencing material. Areas treated in this way will help retard the progress of salt encroachment and can later be returned to grazing if required, when regrowth is out of grazing reach.

Examples

At Ranfurly Park we have set aside some 324 ha, of the total 11,020 ha property, as flora and fauna reserves since 1941. Some 60 *per cent* of reserves are potentially arable. Examples follow:

Bunynooca and Wandawallah Pools

This reserve is on the banks of the Moore River and is timbered with wandoo, York gum, jam and scrub. It provides cover for about 30 euros, possums and wildfowl. Prior to the training of the river this area carried large numbers of wildfowl. The area suffered severe hailstone damage in 1951 and the pools have largely silted up following the river training.

Merrawalla

This area is mainly rough stoney ground. It is 105 ha in size and is a good example of regeneration. By 1958 much of the timber had died or been killed by fires. We put a burn through it and closed it off from stock. As a result hundreds of young trees have appeared providing a source of fencing materials while old hollow trees are nested in by owls, parrots and galahs.

The Forest

This reserve of 42 ha is shown on an old map of the property as an area of scrub which had been partly cleared but allowed to grow again. It has a dense cover of salmon gum, wandoo and York gum, perhaps one of the few stands of its type and size in the agricultural areas. It is fenced from livestock and provides cover for numerous birds.

Marri Hills

This location consists of two fenced-off reserves totalling 36 ha. These provide sanctuary for the smaller birds such as blue wrens, robins and the scrub birds that once abounded in the area and are now scarce. About half of this area is arable and due to past clearance has a semi parkland appearance. It contains kangaroo, brush wallaby and echidna, and is also noteworthy for its wildflowers.

Lupin Valley

This area of 121 ha includes some rocky hills with dense dryandra scrub, blackboys and redgum. These, with stands of wattle and redgums surrounding the area, are a haven for white-tailed black cockatoos. The area carries about 100 kangaroo as well as some brush wallaby.

Land Clearing Legislation and the Community

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This submission to the meeting 'Agriculture and the Environment in Western Australia' is representative of the opinions expressed by a wide cross section of the Plantagenet Community representing Local Government; business, farming and the man in the street following the introduction of the State Government's Clearing Legislation earlier this year. It is not intended to try to offer a solution to the Government's problem but to express the point of view of the effect on our community as we see it.

Concern has been expressed at the manner in which the Legislation was introduced. No prior discussion was held with local organisations, such as Local Government, Zone Development Committee, or Farmers organisations, an action which in many cases immediately alienated those from whom the Government should have been seeking support and co-operation. Further, it left whole communities in a state of bewilderment because of the complete reversal of Government policy. After 30-40 years of a policy encouraging land development in known potentially vulnerable areas, suddenly land holders were faced with shattered hopes when their only mistake had been that they accepted the Government's assurance that these areas held a future for them and their children. Concern was the greater in that the Government had set an example by the expenditure of millions of dollars of taxpayers money on its development of War Service Land Settlement farms in this Shire alone, together with ancillary services such as roads, schools, telephone, water, S.E.C. and generally all those things which make a viable and contented community. Its reversal of policy is not only seen as bringing about a rapid decline in the community but without assurance of making very great progress in reducing soil salinity and river pollution. It has in fact encouraged panic clearing in areas adjacent to the defined catchment area because of the fear that it may be their turn next and so land that must have an incidental effect on soil salinity and waterways pollution, but could have remained timbered for some years to come, has been prematurely cleared.

It is felt that insufficient cognizance has been taken of the economic and social affects of this Government policy on the communities involved without any guarantee of success in the control of the problem. A more rational approach would have been to discuss and formulate experimental projects in co-operation with people already resident in the area and whose very livelihood was at stake; rather than say we are going to stop all development and some time in the future we may be able to take action to reverse the present situation of salt build-up. At the moment Government decision seems to pin its hopes on re-afforestation, but it is felt that a situation which is claimed has developed in 10 to 20 years could take hundreds of years to reverse because of the impervious nature of subsoils and the slow leaching action likely to take place in these soils. The opinion is generally held that unless the Government changes its approach we could end up with neither farmlands or potable water and that in the process many viable communities could wither and die.

Although a system of compensation prevails for land holders no monetary contribution can compensate for the loss of good farm lands and no provision has been made to alleviate hardship in affected communities.

A past Director of Agriculture, Dr. T. Dunne, frequently discussed salt problems with the writer and expressed the opinion that in higher rainfall areas such as Plantagenet soil salinity was a passing phase associated with land development and that the source would be leached away when development stabilised; a contention that can be substantiated to some degree in areas where clearing has been static for a number of years, and here I refer to experience in our own locality. Unfortunately the recent series of years with a below average winter rainfall pattern is an element that does nothing to assist this process.

I have not substantiated my submission with any figures but would point out that 136 or 23 *per cent* of the farming properties within the Shire of Plantagenet come within the restricted area. On some of these the impact will be slight, others will be barred forever from becoming viable properties and so the process of farm buildup by amalgamation will be accentuated. Plantagenet has lost considerable numbers of residents in the past seven years in spite of some compensating increase in its town population, and so an accelerated loss of people from the rural areas is something that just cannot be afforded.

Regulations Governing Pesticides

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Introduction

Regulations governing pesticides in Western Australia are based on legislation administered by both the Public Health Department and the Agricultural Department. They cover the production, labelling, sale, storage and use of pesticides.

The legislation includes:-

1. Pesticide Regulations (Health Act).
2. Food and Drug Regulations.
3. By-Laws adopted from the Health Act.
4. Poisons Act and Schedules.
5. Agricultural and Related Resources Protection Act.
6. Aerial Spraying Control Act.

The objectives of the legislation are:-

1. To protect the health and safety of users.
2. To safeguard public health.
3. To safeguard the environment.
4. For the protection of crops and other farm produce.

I intend to restrict my paper to legislation administered by the Public Health Department which relates to the first three objectives listed.

Health and Safety of Users

The registration of pesticides, which is conditional on satisfactory toxicity data, type of container and labelling details, has as its prime objective the occupational safety of the user, and secondarily the safety of the environment. The provisions of two sections of the Pesticide Regulations are worth recording to elaborate on the aspect of user safety. The Commissioner of Health may refuse to register, or may cancel the registration of, a pesticide formulation which, in the opinion of the Pesticide Advisory Committee, is advisable on one or other of the following grounds:-

a. toxicity, physical properties, formulation, recommended usage, or if for any other reason whatsoever is dangerous to health; or

b. prescribes a faulty formula for mixing or diluting; or

c. is not suitable for the purpose for which it is sold; or

d. is not suitably packed; or

e. for any other reason does not conform to the regulations.

Every package containing a pesticide shall have durably affixed a label, which shall contain the following particulars:-

a. the distinctive name, if any, of such pesticide;

b. the name and business address of the wholesale dealer;

c. the name of every active ingredient and its percentage proportion to the whole;

d. the nett weight or volume as the case may require;

e. directions and precautions for its use.

The label shall not contain any statement, claim, design, device, name or abbreviation which is false or misleading. A person shall not sell a pesticide the label relating to which contains a statement or claim that it is non-poisonous or harmless to humans.

The Protection of Public Health

The Regulations provide that the manufacture, storage, packaging and transport of pesticides shall take place in such a manner that contamination of food should not take place.

Special provisions restrict the use of the more toxic materials such as sodium fluoroacetate, methyl bromide and the cyanide compounds. In the case of sodium fluoroacetate it may only be used for rabbit and wild dog control and strict control is exercised over its use in the field. The commercial use of the fumigants is restricted to people licensed by the Department after approval by oral examination. The wide range of commercial activities ranging from domestic, industrial and agricultural pest control to fumigation procedures is subject to a requirement that the firms be registered and operators licensed. Once again the operator is subject to approval by oral examination. This has helped to standardise and upgrade somewhat the safety and effectiveness of treatments.

It is worth recording that legislation does not prevent a farmer or anyone else for that matter from doing his own pest control provided, of course, the chemicals are available legally to him.

The Food and Drug Regulations provide for an acceptable upper limit of pesticide residue in a wide range of food products. Monitoring of food products is carried out by officers of both the Department of Agriculture and Public Health Department. This checking must serve to reduce excessive and illegal use of pesticides, but its effectiveness is limited as it

Table 1. Merredin farmers blood test for pesticides.

Individual	RBC Chol	Plasma	Heptachlor	DDE	Dieldrin	DDT
M	73	90	Nil*	0.003	0.002	Nil+
D	77	73	Nil	0.002	0.005	Nil
A	74	75	Nil	0.003	0.002	Nil
W	80	68	Nil	0.003	0.002	Nil
R	68	83	Nil	0.002	0.002	Nil
G	71	76	Nil	0.002	0.001	Nil
L	74	96	Nil	0.002	0.003	Nil
AW	78	87	Nil	0.002	0.001	Nil
H	76	71	Nil	0.002	0.003	Nil
Mean	74.5	79.8		0.0023	0.0023	
Range	68-80	68-96		0.002-0.003	0.001-0.005	
Perth PC Operators	80	91	0.006	0.011	0.01	0.004

* Nil = 0.001 + Nil = .002

is only possible to monitor a small percentage of produce. However, the results of testing do not indicate there are current grounds for concern.

Departmental monitoring to check on chemicals with a cumulative effect on people in the pest control industry is carried out to help prevent poisoning. These people are probably the most exposed in the population. In 1978, because of local concern, a small group of farmers in the Merredin area were blood tested for organo-chlorine and also for cholinesterase levels. The findings are presented in Table 1 with a comparison giving the mean values for a group of pest control operators in Perth. The figures for the Merredin farmers can be seen to be very satisfactory.

Environmental Protection

This is achieved to some degree by the phasing out of certain chemicals such as lead arsenate, cadmium compounds, organo-mercurials and restricting the use of persistent pesticides such as the organo-chlorine compounds including dieldrin and DDT. During 1971 and 1972 the P.W.D. organised an interesting survey of underground water in the metropolitan area with a view to ascertaining water levels of organo-chlorine, organo-phosphates and 2,4-D. The levels found were minute (Table 2).

From experience in the Division of Occupational Health it is possible to conclude that the legislation controlling use of pesticides is reasonably effective in 1979. Vigilance and appropriate changes in legislation as new knowledge or use of chemicals accrues is obviously necessary.

Table 2. Underground water survey, Perth metropolitan area.

	Aldrin	YBHC	2-4D	DDE	DDT	Dieldrin	Heptachlor	Organo-Phosphates
May and June, 1972								
Spearwood	<0.0001 ppm	<0.0001 ppm	<0.002 ppm	<0.0001 ppm	<0.0001 ppm	<0.0001 ppm	-	Not Detected
Claremont	"	"	"	"	"	"	-	"
Mt. Claremont	"	"	"	"	"	"	<0.0001 ppm	"
Mt. Lawley	"	"	"	"	"	"	"	"
Balcatta (3 sites)	"	"	"	"	"	"	"	"
Gnangara	"	"	"	"	"	"	"	"
Mullaloo	"	"	"	"	"	"	"	"
September, 1971								
Spearwood	<0.0001 ppm	<0.0001 ppm	<0.002 ppm	<0.0001 ppm	<0.0001 ppm	<0.0001 ppm	<0.0001 ppm	Not Detected
Claremont	"	"	"	"	"	"	"	"
Mt. Claremont	"	"	"	"	"	"	"	"
Mt. Lawley	"	"	"	"	"	"	"	"
Balcatta (1)	"	"	"	"	"	"	<0.003 ppm	"
Balcatta (2)	"	<0.0008 ppm	"	"	"	"	<0.0002 ppm	"
Gnangara	"	<0.0001 ppm	"	"	"	"	<0.0003 ppm	"
Mullaloo	"	"	"	"	"	"	<0.0001 ppm	"

Alcoa Alumina and Agriculture

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Introduction

Alcoa of Australia Limited operates in Western Australia to mine and refine Darling Range bauxite. The Company has refineries at Kwinana and Pinjarra and construction is in progress on a third refinery at Wagerup.

The Kwinana refinery is located on the shores of Cockburn Sound, at the northern end of the Kwinana industrial belt. The Pinjarra and Wagerup refineries, on the other hand, are located in rural situations, and they are surrounded by 5,800 and 4,500 hectares respectively of Alcoa-owned farmlands. These extensive areas of farmland have been secured for two major purposes:

1. To provide an area where the large quantities of residue generated in the refining process can be safely impounded.

2. As a zone to buffer the interface between refinery operations and neighbouring rural areas.

Having acquired the areas with these broad aims in mind, a third goal becomes primary in their management and that is to run the farmlands as profitable and progressive rural enterprises.

Red Mud Disposal

For each tonne of alumina produced approximately 2 tonnes of red mud residue are generated. This residue is deposited in large sealed impoundments or mud lakes built up above the surrounding terrain. While sizes have varied in the past, each future mud lake will cover an area of approximately 50 ha.

During construction and subsequent filling this land is, of course, alienated from rural use. However, when each lake is filled, it will be rehabilitated using techniques developed on mud lakes at Kwinana. The rehabilitation process takes up to 5 years, by the end of which time the mud lake surface is restored to agricultural or pastoral production.

Thus any parcel of land occupied by a mud lake will be alienated from production for several years, but the loss is temporary.

Buffer Zone Management

The land surrounding the Pinjarra and Wagerup refineries serves as a buffer between the refineries and the surrounding agricultural environment. This zone is not intended to form a barrier between Alcoa and the surrounding rural community. Rather it is managed with a view to assimilating the refinery into the existing physical and social environment.

Pastoral/Agricultural Production

Approximately 20 holdings engaged in beef, wool and fat lamb production were purchased in 1969 to form the Company's Pinjarra farmlands. Approximately 40 holdings - largely dairy enterprises - were purchased at Wagerup in 1976-78 to form the Wagerup farmlands. The latter included 485 hectares of irrigated land.

At Pinjarra management of the farmlands has, to the present, concentrated on beef production, whilst maintaining a small flock of sheep for wool and fat lambs.

The beef cattle herd was established initially by purchasing 1,800 Aberdeen Angus, Hereford and Shorthorn breeder cows with a view to increasing to 3,000 breeders. By 1974 the beef herd had risen to 3,500 cows. However, due to a combination of reduced beef prices and a programme to eradicate brucellosis, the herd was reduced to 1,800 and additional steers were then purchased for fattening.

Present strategy is aimed at carrying 2,500 breeder cows and 3,000 breeding ewes. A lot feeding programme has been adopted using oats and lupins grown on the farm, and recent initiatives include the purchase of prime stud cows with a view to developing a Hereford Stud, and a plan to establish a 50 ha trial agroforestry project. This last project is to be a co-operative effort between the W.A. Forests Department, C.S.I.R.O. and Alcoa.

At Wagerup present management is for beef production, with irrigated land used for summer fattening. Friesian cows purchased together with the original holdings are being joined to Angus bulls to develop a crossbred breeding herd.

Other forms of production are to be examined in the near future. Particular attention will be directed to the potential for oil seeds and other crops, making maximum use of areas available for irrigation.

Landscaping

Landscape planting is a major feature on areas of the farmlands leading up to and surrounding the refineries and mud lakes. This work aims at aesthetic improvement of the Company's operations.

At Pinjarra much landscape planting has already been carried out within the refinery site. Efforts are now being directed at making the approach road more attractive by ground shaping and planting a strip bordering this road for a distance of 5 km. Tree and shrub species are being selected for their effectiveness in screening the mud lakes which are, at present, readily apparent from this road, and also for the contribution they can make to the attractiveness of this approach to the refinery.

At Wagerup 9 areas totalling 80 ha were selected for establishment of plantations this year - around the refinery site and future mud lake locations, and along the plant access road. Trees planted on these areas have provided a head start in establishment of screening vegetation.

Next year a further 150 ha scattered over a wide area of the farmlands will be similarly planted to complete the greater part of screening work and landscape enhancement required around the refinery site and its approach road.

Screen and landscape plantings alienate land from pastoral use for a time, as stock are excluded from plantations until the trees are well enough established to withstand trampling or foraging. It is, however, a positive aim to have stock grazing these plantations as early as possible, both to simplify control of ground cover and to return the land to productive use.

Direct Drilling Systems - Their Potential for Increasing Cropped Area Within the Avon Valley With Particular Reference to the Laterite Free Zone.

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Introduction

The adoption of more intensive cropping rotations has been a recent feature of farms in the wheatbelt due to relatively high gross margin for the wheat enterprise compared to sheep and cattle enterprises. Farmers in the Avon Valley have not been able to increase the percentage of the farms under crop because of difficulties associated with topography and soils which restrict working area and increase the potential erosion hazard. These difficulties may be overcome by farmers abandoning conventional cultivation and adopting direct drilling.

Description of the Avon Valley

The district called the Avon Valley consists of four shires: Toodyay, Northam, York and Beverley. The total area of these shires is 749,000 ha. The laterite free zone (Mulcahy 1967) occurs where the valleys of a few rivers have been sufficiently entrenched into the arch of the Darling Range or the country to the east so that lateritic material is absent from the valley sides. The fresh rock which is exposed gives rise to non-calcic brown soils, Dr 2.22 (Dimmock 1960), on the eastern edge or on dolerite intrusions red brown earths Dr 2.33, occasionally podsolics Dy 3.81. On the alluvial deposits farming terraces along the Avon River there are areas of solonized grey soils. These soils are relatively fertile in comparison with other soils occurring in south western Australia which accounts for early development in the region.

The main land surfaces, the York and the Avon surface are distinguished by Mulcahy and Hingston (1961). The York surface occurs on the side slopes of the valley where the lateritic surface has been removed exposing

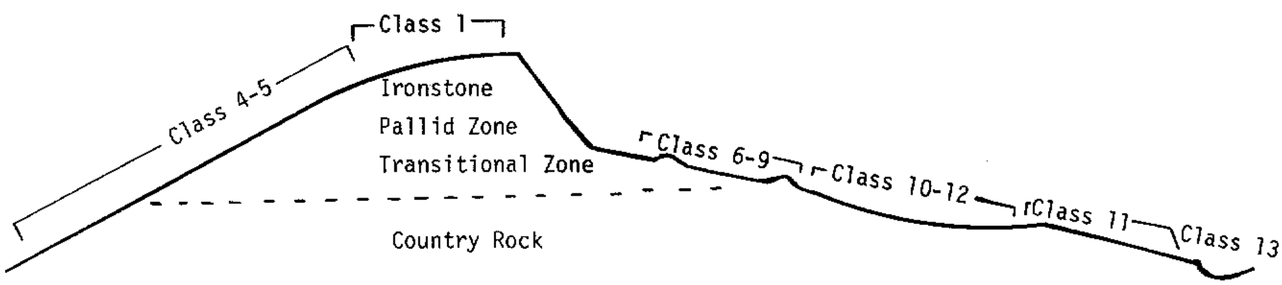

Fig. 1. Land classes after Negus (1978).

Class	1	Ironstone
	2	Breakaway falls and mallet hills
	3	Slopes below mallet hills
	4	Gravelly slopes and ridges
	5	Deep sand hollows
	*6	Grey sandy slopes with scattered granite outcrops
	*7	Red brown loamy soils with scattered dolerite outcrops
	*8	Steep rocky hills
	*9	Granite bosses
	*10	Lower slopes - Wandoo
	*11	Valley flats, salmon gum, gimlet
	*12	Natural drainage depressions
	*13	Main creek and river channels.

* Land classes occurring in the Avon Valley.

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fresh country rock. Where the valley is incising into the Belmunging surface of the old plateau it gives rise to the Malebelling series consisting of gritty brown or grey sand to sand loam over sandy clay loam. The York series which is about the same age as the Malebelling can be divided into Y_1, the shallow soils occurring on ridges and spurs; Y_2, with a deeper profile occupying the middle and lower slopes; and Y_3 where the parent material is basic rock.

The Avon surface occupies most of the valley floor and drainage is variable according to the parent material on which the profile has developed and the location of the floor within the topography.

Land Classes

Negus (1978) describes 13 land classes according to the suitability of the land for the predominant purposes in the upper great southern. The land classes which occur in the Avon Valley are land classes 6,7,8,9,11,12 and 13 (Fig. 1).

A useful guide to land capability classification in the Avon Valley is slope. The steeper slopes characterise areas where active erosion is occurring which results in undeveloped profiles, a shallow A horizon over fragmented parent rock (C horizon). Frequently rock outcrops make the area non-arable because of shallow soil, fragmentation of working areas and the risk of high intensity runoff causing erosion.

The middle and lower slopes are of sufficiently low gradient that rate of soil formation exceeds soil loss resulting in the development of mature profiles, consisting of well developed A, B and C horizons.

The Avon surface is developed on alluvial deposits which have few restrictions except where water logging occurs.

A land capability classification of the Avon Valley has been suggested by Janes (unpublished). This is summarised in Table 1.

Application of the land use capability classification to the Muresk Agricultural College property where conventional cultivation is undertaken shows that about 53 *per cent* of the property is arable, about 17 *per cent* of

Table 1. Land capability classification, Avon Valley.

Class	% Slope	Other Restrictions	Use
Class 1a)	0-3	Nil.	Rotation continuous crop.
b)	0-3	Water logging on occasions.	C*-P*.
Class 2a)	3-8	Nil.	Rotation C - P - P. Contour banks.
b)	3-8	Erosion present. Rock outcrops.	Rotation C - P - P - P. Contour banks.
Class 3a)	8-12	Nil.	Rotation C - P - P - P. Contour banks.
b)	8-12	Rock outcrops.	Occasional crop only. Contour banks.
Class 4a)	>12	Nil.	Occasional crop.
b)	>12	Rock outcrops.	Permanent pasture.
Class 5	Granite bosses		Useful as water catchment.
Class 6	Depressions		Remain uncleared and uncultivated.

* C = Crop. * P = Pasture.

Land capability classification based on description of land surfaces (Mulcahy and Hingston 1961) and description of land classes (Negus 1978). (See Table 2 for comparisons).

the property is available for cropping in any year if a desirable long term rotation is maintained while a maximum area available over a short period would be 21 *per cent* (see Table 3).

Table 2. Comparability of classifications.

Class	% Slope	Land Surface* (Mulcahy & Hingston 1961)	Land Class (Negus 1978)
Class 1a)	0-3	A; Y_2	11
b)	0-3		
Class 2a)	3-8	Y_2; Y_3	7
b)	3-8	Y_3	
Class 3a)	8-12	Y_1; Y_3	7
b)	8-12	Mg_1	6
Class 4a)	>12	Y_1; Mg_1	8
b)	>12		
Class 5	Granite bosses		9
Class 6	Natural depressions		12; 13

* A = Avon Surface. Y = York. Mg = Malebelling.

Direct Drilling Systems

Their Potential for Soil Conservation

One problem which occurs when considering this work is that of the changes in terminology which have occurred over recent years. The following definitions are accepted at the moment:-

Conventional cultivation is the normally accepted ground preparation for a district.

Reduced cultivation is any series of operations which are substantially less than conventional cultivation. This may be only one cultivation followed by sowing with appropriate application of herbicide before or after sowing.

Direct drilling is any technique involving the drilling of seed directly into undisturbed soil. It is usually carried out in this State by a rigid tyned conventional combine, a modified combine or a triple disc drill.

It is well known that conventional cultivation practices increase soil loss by destroying crop residues and vegetative cover, reducing soil structure and infiltration of rainfall with concomitant increase in runoff and soil loss. Direct drilling in particular reduces soil disturbance and erosion risk. This reduction in soil erosion may allow intensive cropping of areas of high erosion risk. A paddock which has not been cropped for 15 years at Muresk with slopes of 8-14 *per cent* has been cropped in 1979. A dry season has meant that there has been no evaluation of erosional losses. Fig. 2 shows the soil conservation benefits of minimum tillage and no-tillage (direct drilling).

Table 3. Alternative management strategies.

Rotation	Desirable Rotation Conventional Cultivation		Maximum Rotation in the Short Term		Direct Drilling	
	Area	% Total	Area	% Total	Area	% Total
1:1	0	0	20.2	2.25	438.2	48.75
1:2	46.8	5.21	78.5	8.73	36.7	4.08
1:3	50.5	5.62	64.8	7.21	0.0	0.0
1:4	48.6	5.41	16.9	1.88	0.0	0.0
1:5	0.0	0.0	9.3	1.03	0.0	0.0
1:10	5.9	0.66	1.4	0.16	0.0	0.0
TOTAL	151.8	16.90	191.1	21.26	474.9	52.83

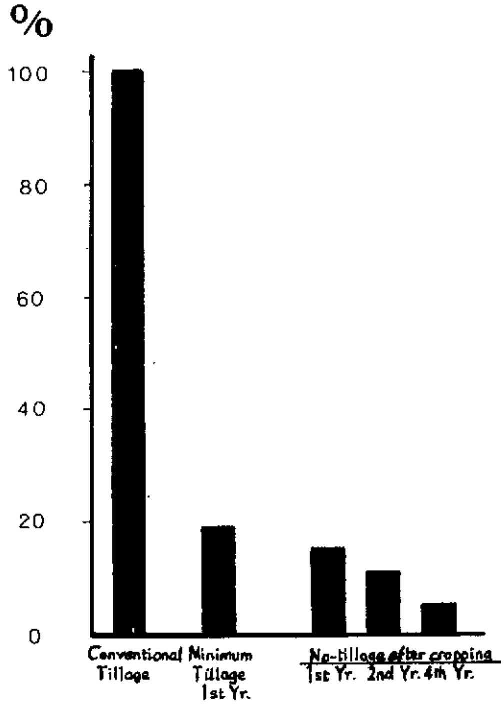

Fig. 2. Soil loss percentages under various tillage practices on a 10 *per cent* slope silt loam soil in U.S.A. (Wischmeier 1973).

Using direct drilling, it is considered that the area presently available for cropping could be sown each year. This would double the area available to cropping from 23 *per cent* to 49 *per cent*. A further 4 *per cent* of the Muresk property which is now considered non-arable, would become available for cropping on a 1:2 rotation (see Table 3).

The 1910 figures in Table 4 reflect the percentage of cleared land at that time. Aerial seeding and top-dressing of superphosphate after World War II increased the area utilised for sown pastures and stock production.

Table 4. Land use in the Avon Valley.

Year	Category	Percentage of cleared land
1910	Under crop	43
	Under fallow	25
	TOTAL	68
1929	Under crop	30
1939	Under crop	27
1957	Under crop	18
1979	Under crop	29

There is good reason to believe that the Muresk property is an average landscape for the Avon Valley between Beverley and Toodyay so there is obvious scope for increasing the arable area under crop by between 10-20% with the adoption of direct drilling systems.

Agronomic considerations

Reduced tillage and direct drilling offer a high degree of flexibility within a cropping system. The extent of multiple cropping has greatly increased overseas due to direct drilling (Marston 1978). Less time is required to sow the crop. This improves timeliness, reduces labour costs and resulting time savings give the farmer a choice between increasing the area under crop or devoting more time to other enterprises.

Yield

A long term tillage trial commenced at Muresk in 1976, comparing conventional cultivation with combine direct drilling and triple disc drilling on the yield of wheat (see Table 5).

Observations began in 1971 and continued in 1972, 1973 and 1979 when paddocks were direct drilled (see Table 6). Yields from areas combine direct drilled have always been equal to those sown by the conventional plough - workback - sow system. Generally the triple disc drill sown crops have not performed as well in the long term tillage trial.

Weeds

Under paddock conditions satisfactory control of weeds has been achieved where sprayseed has been used. A high grazing pressure was maintained in the year prior to cropping, over summer and following the break of season, to control weeds and provide satisfactory conditions for the application of sprayseed.

In the long term tillage trial weed control has been unsatisfactory because of the difficulty of stocking the area in the year the plots are out of crop. Plants which are not normally weed problems in conventionally sown crops have caused serious competition. These weeds are silver grass (*Vulpia* spp.) and Patersons Curse (*Ecklium plantagineum*). Delaying the application of the herbicide until after a full germination of silver grass appears to give effective control of the grass, while a post emergent herbicide such as Linuron or 2,4D adequately controls Patersons Curse.

Other Considerations

Workability

Workability of a paddock is related to access and ease of working. Access to Avon Valley paddocks is restricted during wet periods under conventional cultivation systems. This makes weed control or pest control difficult where pre-emergent spraying is required. Where direct drilling is used, access is easier as a fibrous root mat holds the soil together and reduces bogging problems. In very wet years such as 1963 and 1974, it proved difficult to sow the crop by conventional means.

Table 5. Cultivation trial at Muresk.

a. Yield Results

Year	Treatment	Mean Yield (tonnes *per* ha)			
		Continuous Wheat		Pasture:Wheat	
		+N	-N	+N	-N
1976	Conventional Cultivation			3.37	2.64
	Direct Drilled Combine			3.09	2.61
	Direct Drilled Triple Disc			3.12	2.51
1977	Conventional Cultivation	1.07	1.25	1.03	1.45
	Direct Drilled Combine	1.33	.96	1.96	1.59
	Direct Drilled Triple Disc	0.70	.55	1.62	0.80
1978	Conventional Cultivation	1.57	0.68	2.02	1.22
	(Standard error)	(0.08)	(0.16)	(0.10)	(0.04)
	Direct Drilled Combine	1.57	1.05	1.85	1.30
	(Standard error)	(0.43)	(0.39)	(0.19)	(0.15)
	Direct Drilled Triple Disc	0.47	0.25	1.42	0.53
	(Standard error)	(0.08)	(0.09)	(0.26)	(0.10)

b. Analysis of Variance

Source	S.S.	df	M.S.	F*
1977				
Blocks	379,835.16	2	189,917.58	2.6 ns
Nitrogen	239,067.11	1	239,067.11	3.37ns
Error	141,876.56	2		
Main Plot TSS	760,778.85	5		
Rotation	1,736,245.44	1	1,736,245.44	19.35**
Rotation x Nitrogen	336,682.55	1	336,682.55	3.75ns
Error	358,742.16	4	89,685.54	
Subunit S.S.	3,192,449			
Tillage	1,794,587.16	2	897,293.58	8.89***
Nitrogen x Tillage	1,179,736.89	2	589,868.44	5.85ns
Tillage x Rotation	536,272.73	2	268,136.36	2.65ns
Nitrogen x Tillage x Rotation	55,398.44	2	27,699.32	
Error	1,613,894.8	16	100,824.6	
TSS	8,730,881	35		
1978				
Blocks	1,462,122.4	2	731,061.2	2.04ns
Nitrogen	3,715,256.3	1	3,715,256.3	10.4 ns
Error (a)	714,185	2	357,256.3	
Rotation	1,878,270.25	1	1,878,270.2	5.8 ns
Rotation x Nitrogen	92,517.4	1	92,517.4	0.28ns
Error (b)	1,295,924.2	4	323,981.8	
Tillage	4,374,655	2	2,187,377	7.12**
Rotation x Tillage	188,158.3	2	94,079.1	0.31ns
Nitrogen x Tillage	186,216.2	2	93,108.1	0.30ns
Nitrogen x Rotation x Tillage	249,535.5	2	124,767.7	0.40ns
Error	4,912,994.48	16	307,062.15	
TSS	19,069,834.98	35		

*ns Not significant ** Significant 97.5% confidence level *** Highly significant.

Table 6. Summary of paddock yields; Muresk cultivation trial.

Year/ Paddock	Cultivar	Cultivation	Fertilizer (kg ha) N	P	Date Sown	Weed Control	Yield (t ha)
1971/72							
Bank	Gamenya	Sprayseed CDD		5	16/6	Nil	1.6
Adjoining	Gamenya	Conventional		5	14/6	Nil	0.7(frost)
					Farm Average	-	1.25
1972/73							
½ Sub	Gamenya	Sprayseed CDD		4	20/6	Nil	1.4
½ Sub	Gamenya	Conventional		4	20/6	Nil	1.5
					Farm Average	-	1.36
1973/74							
Sub	Gamenya	Sprayseed CDD	25	5		Nil	2.05
					Farm Average	-	2.04
1978/79							
Sub	Gamenya	Sprayseed CDD	14	14		Nil	1.95
	Gamenya	Sprayseed TDD	14	14		Nil	2.36
					Farm Average	-	2.07

The yield data indicates that satisfactory wheat crops can be grown using the combine direct drilling technique.

Ease of working is enhanced by large working areas with long leads. The wheatbelt farmer can crop areas of 100-200 ha or more without obstacles whereas the Avon Valley farmer is restricted by small paddocks further cut by obstacles to cultivation such as depressions, rock outcrops and contour banks. Molnar (1970) showed a loss of efficiency due to reducing the working area from 60 to 20 ha and lead length by 400 m was 14 *per cent* for initial ploughing, 11 *per cent* for working back and 7 *per cent* for seeding. The limited size of the croppable areas in the Avon Valley also limits the cost economies which can be achieved by using large machinery. This puts the wheatbelt farmer in an advantageous position with respect to his Avon Valley counterpart. Direct drilling offers the Avon Valley farmer the means of reducing the cost disadvantage he suffers in cropping in comparison to the wheatbelt.

Energy, Fuel and Labour Saving

Considerable saving in energy, fuel and labour has been reported elsewhere in Australia and overseas but work remains to be done on these aspects under Western Australian conditions.

In a trial examining different levels of cultivation over a 4 year period Hutchings (1974) showed that fuel required for establishing winter cereal crops from direct drilling was 67 *per cent* of the conventional 3 month fallow. Savings on labour inputs were of a similar order. Green and McCulloch (1976) showed that the typical value for the amount of energy required in carrying out a mechanical weeding operation is 0.56 G T/ha (1.5 gals diesel fuel/acre) which compares with 0.056 G T/ha (0.15 gals diesel/acre) for a typical weed control spraying operation. Direct drilling and minimum tillage techniques, using herbicides to control weeds save 1 G T/ha of total energy (equivalent to 30ℓ of diesel fuel/ ha).

Conclusion

The adoption of direct drilling systems on farms in the Avon Valley would enable farmers to cash in on high returns being achieved by grain growing enterprises by allowing more land to be put more frequently under crop without adding to erosion risks. Providing weed control can be achieved, combine direct drilled crops yield about the same as those established using conventional cultivation.

Many of the problems associated with cropping in the Avon Valley such as access and convenience of working and lack of economies of scale are offset by direct drilling.

Significant cost savings are inherent in direct drilling systems compared to conventional cultivation. Further work urgently needs to be done on energy, fuel and labour saving which can be achieved by using direct drilling in the Avon Valley.

References

Avon Valley Development Committee (1958). 'Agriculture in the Avon Valley, 1958'. (Govt. Printer: Perth).

Green, M.B. and McCulloch, A. (1976). Energy considerations in the use of herbicides. *J. Sc. Food Agric.*

Hutchings, R.J. (1974). Tillage and crop production. Annual Report, C.S.I.R.O. Division of Plant Industry.

Marston, D. (1978). 'Reduced tillage systems - Their potential for soil conservation'. *J. Soil Conserv. Serv. N.S.W.*

Mulcahy, M.J. (1967). Landscapes, laterites and soils in south-western Australia. In J.M. Jennings and J.A. Mabbutt Eds. 'Land form studies from Australia and New Guinea'. (A.N.U. Press: Canberra).

Mulcahy, M.J. and Hingston, F.J. (1961). The development and distribution of the soils in the York-Quairading area, Western Australia, in relation to landscape evolution. C.S.I.R.O. *Soils Publication*, No. 17.

Molnar, I. (1970). The effect of working area and length of lead on efficiency of working various implements. International training course in the conservation of natural resources. (Department of External Affairs and Department of Conservation, N.S.W. April-July 1970).

McNeill, A.A. and Aveyard, J.M. (1978). Reduced tillage systems - Their potential for soil conservation. *J. Soil Conserv. Serv. N.S.W.*

Negus, T.R. (1978). Land classes in the upper Great Southern of Western Australia. *West. Aust. Dept. Agric. Bulletin* 4010.

Reeves, T.G. and Ellington, A. (1974). Direct drilling experiments with wheat. *Aust. J. Exp. Agric. Anim. Husb.* 14 (273).

Stonebridge, W.C., Fletcher, I.C. and Lefroy, D.B. (1973). Sprayseed - The Western Australian Direct Saving System. Outlook in Agriculture 7 (155).

Wischmeier, W.H. (1973). Conservation tillage to control water erosion. In 'Conservation Tillage' p.133-140. (Soil Conservation Society of America).

Effects of Land Use Changes on Salt and Water Transport

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Introduction

Studies of the effects of land use change on salt and water transport are conducted by CSIRO in nine small catchments in the Darling Range. The paired catchment approach is used in three sets of catchments in the 1100 mm, 700 mm and 600 mm annual rainfall zones west of Collie, east of Collie and at 'Yalanbee', Bakers Hill, respectively. Non-paired catchments are monitored at Del Park (1350 mm *per annum*, bauxite mining) and at 'Yalanbee' (agriculture). In all except one catchment, hydrologic measurements have been made both before and after the clear felling of the dry sclerophyll forest for the development of agriculture or extraction of bauxite. Measurements include quality and quantity of streamflow, rainfall, and groundwater, plus soil water content (to 6 m) and soil salt storage.

This communication summarises some of the research findings recently published in much greater detail elsewhere (Williamson and Bettenay 1979; Johnston *et al* 1979; Sharma *et al* 1979). As preliminary results and interpretations are also included, it is requested that the authors be consulted before data are referenced, reproduced or used in other analyses.

Salt Storage

The quantity of salts stored in the landscape is a significant factor in the maintenance of salt redistribution to streams. In Table 1 the average salt storage of the soil profile is given as the measured chloride content in CSIRO research catchments. Values are the average of five holes, cored in most cases to bedrock, except for Yalanbee where data for nineteen holes were used. Sodium and chloride contribute 80 *per cent* of all ions in solution. The similarity of the ionic composition of solutes to rainfall, plus the long and intensive period of leaching associated with the laterite formation, support the conclusion that the salts at present stored in the landscape are derived from atmospheric accession in rainfall. The ratio of chloride input in rainfall to stored chloride is 0.0025 *per annum* for Wights catchment, and 0.00015 *per annum* for Lemon catchment.

Table 1 shows that chloride storage increases with decreasing average rainfall, as does the average chloride concentration of the soil water since there is little difference in average soil water content with decreasing

Table 1. Average salt storage (as chloride ion) in CSIRO research catchments.

Catchment	Average Rainfall (mm yr^{-1})	Rainfall $C\ell^-$ Conc. (mg ℓ^{-1})	Profile Depth (m)	Chloride Storage (kg m^{-2})	Average $C\ell^-$ Conc. of Soil Water (mg ℓ^{-1})	Average Water Content (m^3 m^{-3})
Del Park	1350		10.8	0.7	100	.38
Wights	1100	6.5	13.7	2.7	620	.32
Salmon	1100	6.4	19.1	5.4	830	.34
Lemon	750	4.2	25.4	20.7	2580	.32
Dons	700		18.7	27.8	5120	.29
Ernies	700		28.9	22.9	3650	.22
Yalanbee*	600	5.1	22.5	51	-	-

* Source: Dimmock *et al* (1974) using $C\ell$/TSS = 0.54

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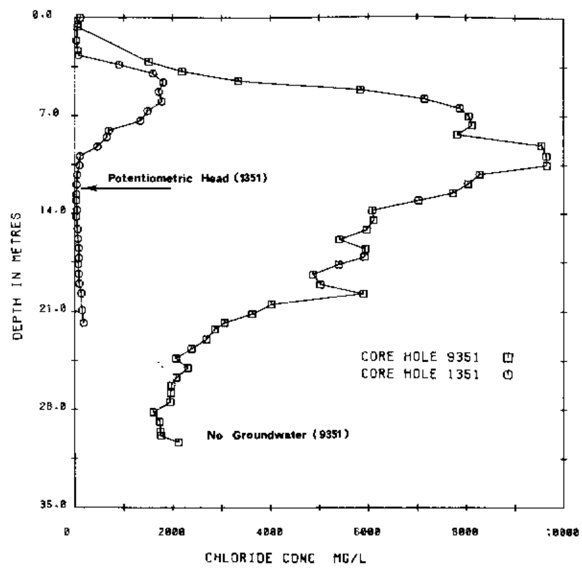

Fig. 1. Chloride concentration in soil water.

rainfall. Under forest conditions, most of the solute is found in the unsaturated zone. An analysis of 161 bore holes drilled in the Manjimup Woodchip License Area showed similar trends where rainfall is <1050 mm *per annum*, with salinity parameters varying also with depth and topographic position.

Figure 1 shows the characteristic shape of the chloride concentration of soil water as a function of depth for the cored holes in five Collie catchments. Core hole 1351 is from Salmon catchment which is in a higher rainfall area than core hole 9351 from Lemon catchment. The 'bulge' type profile is the most universal, particularly where there is permanent groundwater, the peak concentration being close to but above the water table. There appears to be a correlation between root distribution and the solute profile. The peak concentration becomes smaller and closer to the soil surface with increasing rainfall. Another typical solute profile found elsewhere in the Darling Range, particularly in higher rainfall areas, has a monotonic increase with depth.

The greater salt storage observed in areas of lower rainfall is not reflected in the groundwater salinities for forested land. Average salinities of groundwater for Wights and Lemon are 540 and 500 milligrams of chloride *per* litre (mg $C\ell^{-}\ell^{-1}$) respectively. This may be changed following clearing. Hence, pre-clearing groundwater salinities may not indicate the potential increase following clearing which salt storage would suggest, particularly when the groundwater level rises into the 'bulge' zone.

Salt and Water Balances

Salt and water are received by the catchments in rainfall and lost from the catchments in streamflow and groundwater flow, in addition water is lost by evaporation. The stream may be made up of runoff, near surface groundwater perched on the clays, and groundwater from the deeper clay aquifers. Use can be made of the differences (a factor of about 10^2) in chloride concentration of these waters to estimate the volumetric contribution of each source to the stream.
Table 2 gives data for the outflow/inflow ratio of water and chloride for catchments at Bakers Hill and Collie. Tables 3 and 4 give the data leading to the calculation of the ratios in Table 2. The steady state condition for chloride is when the outflow:input ratio is 1.0. A catchment may be accumulating chloride when the ratio is less than 1.0 but where this occurs it is known that there is groundwater flow in the deep clay aquifer (often saline) across the lower boundary of the catchment. However for Wights and Salmon catchments, the weirs are built on the basement rock so that streamflow includes all the groundwater flow from the catchment. With these catchments, under a land use of production forestry, there was a net loss of chloride.

As the name implies, the Subdued Drainage catchment (area 80.3 ha) has a poorly defined stream line, and contrasts with the quite deeply incised streams of the other Yalanbee catchments. In the Subdued Drainage catchment, the increase in chloride flow/fall ratio was directly related to the contribution of saline groundwater to the stream when the potentio-

Table 2. Outflow:inflow ratios for water and chloride ion in small experimental catchments.

Year*	Streamflow : Rainfall Ratio						Chloride Outflow : Chloride Input Ratio					
	Subdued Drainage	Yalanbee		Collie Catchment			Subdued Drainage	Yalanbee		Collie Catchment		
		East	West	Lemon	Wights	Salmon		East	West	Lemon	Wights	Salmon
1968		.136	.020					1.29	0.27			
1969	.006	0	0				0.06	0	0			
1970	.020	.005	<.001				n.a.	0.05	<0.01			
1971	.010	.003	0				0.34	0.02	0.0			
1972	.033	.006	0				1.6	0.07	0.0			
1973	.079	.042	.002				4.2	0.34	0.02			
1974	.124	.063	.057	.053	.230	.249	5.9	0.52	0.57	0.33	2.4	2.3
1975	.082	.046	.050	.006	.079	.078	23.6	0.41	0.63	0.06	2.0	1.3
1976	.024	.009	.020	.001	.023	.023	8.2	0.10	0.25	0.01	1.5	1.1
1977		<.001	.004	.011	.180	.077		<0.01	0.05	0.11	4.8	1.6
1978				.035	.228	.078				0.27	7.4	1.2
Catchment Management	Cleared by 1963	Uncleared Control	Cleared Dec '73	Partly Cleared Mar '77	Cleared Apr '77	Uncleared Control	Cleared by 1963	Uncleared Control	Cleared Dec '73	Partly Cleared Mar '77	Cleared Apr '77	Uncleared Control
		Paired Catchments			Paired Catchments			Paired Catchments			Paired Catchments	
Location	'Yalanbee' Baker's Hill			East of Collie	West of Collie		'Yalanbee' Baker's Hill			East of Collie	West of Collie	

* Data is for water year (April-March) except for subdued drainage catchment for which data is in calendar years. Note that 1978 is incomplete, data available to mid January 1979 only.

Table 3. Water input and output for small experimental catchments.

Year*	RAINFALL in mm						STREAMFLOW in mm					
	Subdued Drainage	Yalanbee		Collie Catchment			Subdued Drainage	Yalanbee		Collie Catchment		
		East	West	Lemon	Wights	Salmon		East	West	Lemon	Wights	Salmon
1968	-	427	427					58.2	8.6			
1969	339	386	386				2	0	0			
1970	522	538	547				10	2.7	0.2			
1971	608	547	562				6	1.7	0			
1972	442	435	451				15	2.8	0			
1973	668	643	671				53	27.2	1.2			
1974	760	731	745	976	1390	1467	94	46.0	42.3	51.5	320	366
1975	650	777	765	740	1028	1059	53	36.0	37.9	4.7	81	83
1976	590	457	456	544	829	867	14	4.0	9.2	0.7	19	20
1977		484	499	650	905	964		0.3	2.2	7.1	163	74
1978				723	947	979				25.2	216	76

* Data are for water year (April-March) except for Subdued Drainage catchment for which data are in calendar years.

Table 4. Chloride input and output for small experimental catchments.

Year*	CHLORIDE FALL IN RAINFALL kg ha^{-1}						CHLORIDE OUTPUT IN STREAMFLOW kg ha^{-1}					
	Subdued Drainage	Yalanbee		Collie Catchment			Subdued Drainage	Yalanbee		Collie Catchment		
		East	West	Lemon	Wights	Salmon		East	West	Lemon	Wights	Salmon
1968		21.7	22.2					27.9	6.1			
1969	21.0	19.6	20.0				1.2	0	0			
1970	32.4	27.3	28.4				n.a.	1.5	0.1			
1971	40.2	33.4	34.5				14.1	0.7	0			
1972	29.3	22.6	23.4				46.0	1.6	0			
1973	39.3	37.3	39.0				167.4	12.5	0.9			
1974	43.3	40.0	41.8	45.2	85.6	91.8	254.2	20.6	23.8	14.8	206	211
1975	35.2	36.0	37.6	29.0	68.4	80.8	829.6	14.7	23.7	1.7	136	105
1976	37.0	15.6	15.9	18.5	53.3	44.4	302.8	1.6	3.9	0.2	79	50
1977		22.0	23.7	26.9	60.8	57.6		0.1	1.1	3.0	292	90
1978				32.8	62.4	67.0				8.9	463	80

*Data are for water year (April-March) except for Subdued Drainage catchment for which data are in calendar years.

metric head was less than 1 m below ground surface after 1972.

In 1968-69 the salt content of the sandy/gravelly soil (0.73 m depth) above the deep clay was 450 kg $C\ell^{-}ha^{-1}$ (30 sampling sites). For the 1972-76 period when chloride outflow/input ratios exceeded unity, the catchment contributed 1416 kg $C\ell^{-}$ ha^{-1} to the saltflow. Thus the salt storage in the more permeable surface soils was not sufficient to account for the net loss of salt. Between 1969 and 1976 annual flow-weighted concentration of stream flow increased from 60 to 2630 mg $C\ell^{-}$ ℓ^{-1}.

The post-clearing results for West catchment and Wights catchment show an immediate increase in output of both chloride and water following clearing based on the correlation with the paired control catchment. For West catchment the increase has been about one order of magnitude, while in Wights catchment streamflow has increased by a factor of 2.4 in 1977 and 3.1 in 1978, and chloride flow increasing by a factor of 2.7 in 1977 and 4.9 in 1978. The flow-weighted annual average concentration of chloride in streamflow for Wights was 64, 167, 422, 177 and 216 mg ℓ^{-1} for the years 1974-78 respectively, showing that increased runoff has kept the average salinity within acceptable levels. However, the rate of increase in chloride flow is greater than in streamflow suggesting a consequent increase in average salinity. A number of seepage zones existed in both Wights and Salmon catchments before clearing, those in Wights having expanded in the two post-clearing years. In the West catchment at Yalanbee, to date, no seepage of saline groundwater has developed since clearing.

In Wights, 70 *per cent* of the increase in chloride output occurred in the 3 months following the first major runoff event in May (1978) or June (1977). The increase in the proportion of rainfall passing directly to the stream in runoff accounts for less than 4 *per cent* of the increased chloride outflow.

Assuming that the present outflow:inflow ratio of 7.4 is maintained the removal of stored salt and attainment of a new equilibrium condition would take in the order of 70 years for Wights catchment.

A different approach has to be used to establish the effect of clearing on salt and water outflow for Lemon catchment due to a poor correlation with the catchment monitored as its uncleared pair. Based on catchment outflow response to rainfall, there appears to be an increase in both salt and water output following clearing. The major area for runoff generation is the broad flat valley floor of 35 ha extending about 900 m upstream from the gauging station. The streamflow in 1975 could be generated by a runoff:rainfall ratio of 0.06 for that valley floor, but in 1978 with similar rainfall the ratio was 0.34. With the flow weighted chloride concentration of streamflow similar for those two years, the net chloride output was greater by a factor of 5.4 in 1978. Groundwater, at 1000 mg $C\ell^{-}$ ℓ^{-1} is at a depth greater than 16 m below the soil surface in the valley floor and does not contribute to the stream.

For the three catchments subjected to clearing, salt accumulated in surface soils appears to be more important than saline groundwater as the source for the increase in salt export during the immediate post clearing years. The increase in baseflow (Wights) and the development of seeps (Wights, and eventually Lemon and West), expected as a consequence of rising groundwater levels already observed, will probably contribute a smaller volume than the increased runoff already occurring. However, due to the high chloride concentration of the groundwater at existing and potential seepage locations (of order 750 mg ℓ^{-1} in Wights, 1000 mg ℓ^{-1} for Lemon, and 11,000 mg ℓ^{-1} for West catchment at Yalanbee), the effect on stream chloride concentration is expected to be more significant. The salt storage in the upper soil layers will contribute to increased stream salt output for a relatively short period of time (around 10 years), but the high salt

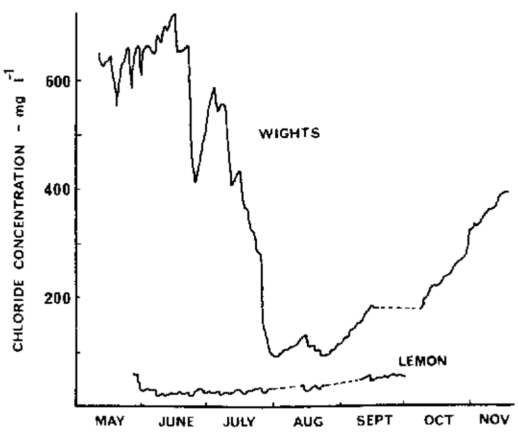

Fig. 2. A comparison of the pattern of chloride concentration of streamflow in 1975 for Wights Catchment (includes seepage) and for Lemon Catchment (no seepage).

storage which would be mobilised by a rising water table would provide a more sustained contribution to stream salinity (say about 100 years). The extent and duration of contributions to stream salinity from the various sources as a function of time, when available for these and other experimental catchments, will help to clarify their relative importance. The use of differences in chloride concentration of the various sources of stream water is being examined as a tool for establishing the relative contribution of the sources.

Solute Composition as an Indicator of Flow Pathways

The large differences of chloride concentration in runoff (<10 mg ℓ^{-1}), of shallow perched groundwater (<200 mg ℓ^{-1}) and of deeper, usually saline, groundwater (>200 mg ℓ^{-1}) allow the annual pattern of stream chloride concentration to indicate sources of water for the stream even under forest vegetation.

Figure 2 shows the contrasting patterns for stream chloride concentration with (Wights) and without (Lemon) a saline groundwater contribution. The high concentration of the initial streamflow in Wights indicates the dominance of seepage contribution; the subsequent reduction resulting from an increasing volume of runoff generated by winter rainfall. The steady increase in concentration for the remainder of the year reflects the contribution from shallow groundwater and the increasing proportion of saline groundwater contributing to streamflow. With no contribution from saline seepage, the fluctuation in streamflow concentration for Lemon is only marginally affected by runoff events.

The annual variation of stream chloride concentration should be a useful tool for making a preliminary assessment of the salinity hazard of induced hydrologic changes in a forested catchment, and for gauging the effectiveness of methods used to reduce or eliminate seepage in a farmed catchment.

Applying the principle of conservation of mass, it can be shown that -

$$C_s V_s = C_r V_r + C_u V_u + C_g V_g$$

where C is solute concentration and V is the component volume in the streamflow with the subscripts being streamflow, s, runoff, r, through flow in surface sandy or gravelly soil layer, u, and groundwater, g. In many situations the groundwater flow component in streamflow is only part of the total groundwater flow from a catchment. Sharma *et al* (1979) have taken chloride concentrations measured in several catchments to estimate the contribution of solutes to the stream from various sources within the landscape. The analysis suggests that with a change in land use from forest to agriculture, not only will there be a significant increase in the contribution from groundwater and/or the upper soil layer, there may also be increased contribution from surface runoff. Based on the analysis applied to a hypothetical catchment and two experimental catchments, it is suggested that land clearing may cause a significant increase in any of the three components depending on the configuration of the catchment, solute distribution in the profile and differential hydraulic properties of various sub-components of the catchment. It is unlikely that either the rising groundwater or throughflow hypotheses for salinity development put forward by Wood (1924) and Conacher (1975) respectively, could be shown to be exclusive. In many catchments, a flow model which includes the two pathways in a dynamic form may be more realistic.

Changes in ionic composition of catchment waters provide a useful tool for analysis of hydrologic response. On an annual basis, the differences of ionic composition of the various sources of water for streams appear to be too small for quantitative analysis. However the seasonal changes, using ion to chloride ratios, appear to be significant particularly for SO_4^{--}, K^+, Ca^{++} and Mg^{++}. By comparison with rainfall (or throughfall), ratios of K^+, Ca^{++} and SO_4^{--} with chloride are significantly reduced as a result of downward redistribution of water to the groundwater system, leading to groundwater ratios being the lowest in the hydrologic system. Consequently, the lowest ratios for streamflow reflect a high proportion of groundwater in streamflow, and the highest ratios (and lowest Si content) correspond with periods of maximum runoff.

Analysis of seasonal changes in ionic composition is continuing. Some other general results are:-

1. The pH ranges from 3.5 to 4.0 in the unsaturated pallid zone, but from 5 to 7 in the deeper weathering zone, the higher values being associated with saturated soil.

2. The higher $SO_4^{--}/C\ell^-$ ratio for rainwater compared to seawater suggests an effect of regional industrial activity. Higher $K^+/C\ell^-$ ratios may be due to forest fires. Ratios of ions to chloride in rainfall differ significantly from the ratios of throughfall for all major ions except Ca^{++}. In addition $C\ell^-$ concentration is higher in throughfall than in rainfall.

3. Ratios of total extractable ions to chloride for soils are higher than the ratio for rainfall. However, the ratios for soil saturation extracts are significantly lower than for rainfall. This indicates that the soil profile is adsorbing ions such as K^+, Ca^{++}, Mg^{++} and SO_4^{--}.

References

Conacher, A.J. (1975). Throughflow as a mechanism responsible for excessive soil salinisation in non-irrigated, previously arable lands in the Western Australian wheatbelt: a field study. *Catena* 2, 31-67.

Dimmock, G.M., Bettenay, E. and Mulcahy, M.J. (1974). Salt content of lateritic profiles in the Darling Range, Western Australia. *Aust. J. Soil. Res.* 12, 63-69.

Johnston, C.D., McArthur, W.M. and Peck, A.J. (1979). Distribution of soluble salts in soils of the Manjimup Woodchip Licence Area, Western Australia. Submitted for publication in Division of Land Resources Management Technical Paper series.

Peck, A.J. (1978). Salinisation of non-irrigated soils and associated streams: a review. *Aust. J. Soil Res.* 16, 157-168.

Sharma, M.L., Williamson, D.R. and Hingston, F.J. (1979). Water pollution as a consequence of land disturbance in south-west of Western Australia. Submitted for publication in proceedings of 4th International Symposium on Environmental Biogeochemistry and Leaching Conference, August 1979.

Williamson, D.R. and Bettenay, E. (1979). Agricultural land use and its effect on catchment output of salt and water - evidence from southern Australia. Progress in Water Technology Series (in press).

Wood, W.E. (1924). Increase of salt in soil and streams following the destruction of native vegetation. *J. R. Soc. West. Aust.* 10, 35-47.

Changes in Groundwater Systems After Clearing for Agriculture

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One objective of catchment studies in the Darling Range is to determine characteristics of groundwater systems, and the changes which can be attributed to agricultural development of previously forested land. In this region the native forest is dominated by jarrah and marri (*Eucalyptus marginata* and *E. calophylla* respectively), while the conventional form of agriculture is grazing on annual pastures which germinate in early winter and senesce in early summer.

This note presents a resumé of observations in three widely-separated areas of the Darling Range. The results are preliminary and interpretations may change after the analysis of longer postclearing data sets, chloride concentrations in the groundwaters, details of the bore hydrographs, *etc.*

Observations Near Baker's Hill

In the early 1970's observation bores were drilled in three small catchments on 'Yalanbee' an experimental farm near Baker's Hill, W.A. Average rainfall in this area is about 600 mm *per annum*.

One of the catchments was cleared in the late 1950's and early 60's. Records of the potentiometric head in a saline (chloride ∿ 10^4 mg ℓ^{-1}) aquifer at a depth of 7.5 m begin in May 1969. At that time the head was about 2.1 m below ground level, and was varying seasonally with amplitude of about 0.5 m. Pressure has steadily built up in this aquifer which is now (at least) semi-confined. The potentiometric head reached ground level in 1974, and now stands above it throughout the year. Flow-weighted chloride concentrations in the stream draining this catchment have increased from ∿ 200 mg ℓ^{-1} in 1971 to ∿ 3000 mg ℓ^{-1} in 1976.

The remaining two catchments form a pair, one of which was cleared in December 1973. After the catchments were instrumented for streamflow measurements in 1969, drilling revealed differences in subsurface conditions.

Only four of nineteen bores encountered aquifers in the West catchment before it was cleared. The head of water in all four of these bores has increased since clearing at rates of between 0.5 and 1.6 m *per annum*. Another three bores in this catchment have made water since clearing. In these bores the heads are increasing at between 0.7 and 1.2 m *per annum*. A characteristic of the deeper (∿ 20 m) aquifers in this catchment is that they show little seasonal response. This suggests little recharge and may be associated with the frequency of dry bores. Five of the remaining bores stand on relatively shallow (<10 m) rock and occasionally make water in winter.

By contrast, fifteen out of sixteen bores encountered water in the neighbouring East catchment which remains uncleared. In fourteen bores the head varies seasonally with amplitude ∿ 0.4 m, and increased slowly until 1976. Since then, the trend has been a slow decrease of head. The head in another bore increased slowly from 1973 to 1978 with little (< 0.1 m) seasonal amplitude. The remaining bore in this catchment was dry until 1976, and since then the head has varied erratically with no apparent trend.

Fig. 1 illustrates the hydrograph of one bore from each of the 2 areas in the paired catchment study.

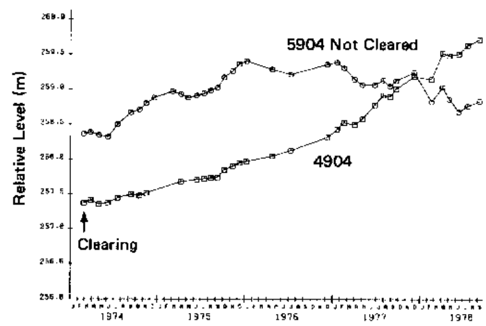

Fig. 1. Hydrograph records of one bore of each of the East and West catchments, paired catchment study at 'Yalanbee'.

Lemon Catchment

This catchment lies about 30 km NE of Collie, W.A. It receives an average rainfall of about 750 mm *per annum*. In the summer of 1976/77 the lower half (about 184 ha) of the catchment was cleared and sown to annual pasture. Groundwaters are observed in deeply weathered granite at depths of ∿ 30 m, and at depths of <5 m in the more permeable surface soils of the laterite profile.

Out of twenty four shallow bores, five have always been dry, and another three have only rarely made water. Five of the shallow bores have been wet every winter since 1975, and another ten have been wet in all but one winter (1976). The remaining bore in this set is only rarely dry. Any effects of clearing on the shallow aquifer are not readily detectable against the variations due to rainfall differences from year to year.

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Three out of nineteen deep (∿ 30 m) bores in the area which is now farmed were dry on drilling; two of these have made water since clearing, and heads are increasing at ∿ 0.5 m *per annum*. In another eleven bores which always intersected the deep aquifer, heads are increasing at rates up to 1.3 m *per annum* (median 0.8 m *per annum*) since clearing. There are significant (amplitude ∿ 0.5 m) seasonal changes in some of the bores. Three of them respond to rainfall, but have not responded to clearing. Another two bores in this catchment show little variation of head in time, either seasonally or since clearing.

Fig. 2 shows the hydrographs of two bores in the cleared area of this catchment; in one bore the head is affected by winter rain, but not clearing, while the other has responded to clearing, but is not influenced by seasonal recharge.

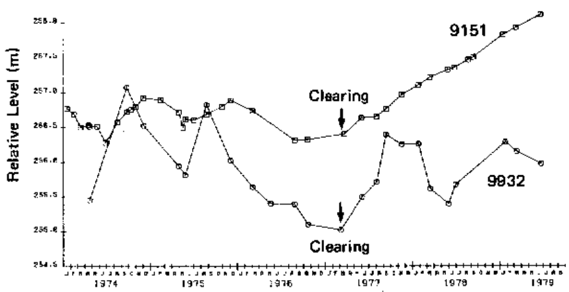

Fig. 2. Hydrograph records of two contrasting bores Lemon catchment, Collie.

Dons Catchment

This catchment lies in the 700 mm *per annum* rainfall zone about 35 km NE of Collie, W.A. It was partly cleared in the summer of 1976/77 in special patterns designed to prevent the development of salinity from groundwater seepage. As in the case of Lemon catchment, not all the borehole data have been examined in the preparation of this note.

The data from eleven bores in uncleared sections of the catchment have been examined. One of them has been dry since drilling, and another two are now dry after holding water until 1976. The head of water is currently falling in another four bores in the uncleared area, and is essentially constant in three more. Since clearing, there has been a small rise in head of water in the remaining bore which is situated in a 30 m wide strip of trees between two 350 m wide strips of farmed land.

The head of water has increased slightly since 1977 in four out of six bores in cleared sections of this catchment, and has remained essentially constant in the other two.

Fig. 3 shows the hydrographs of two bores: one within and the other outside of cleared areas on this catchment.

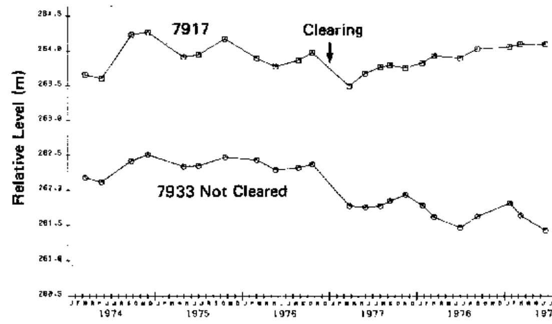

Fig. 3. Hydrograph records of two bores, one in cleared area one not cleared, Dons catchment.

Wights Catchment

This catchment lies about 16 km W of Collie, W.A. in an area of about 1100 mm *per annum* average rainfall. Essentially all of the catchment was cleared in the summer of 1976/77.

Five bores in this catchment are drilled to clay layers at depths of 0.5 to 2.5 m for observations of perched water tables. Two of these bores have been wet only once (in both cases since clearing). The remaining bores make water in winter, but one of them remained dry through 1976. No trends in the head of water in the shallow aquifer can be identified, but perhaps the perched water system develops more frequently and persists for a greater time now than it did before clearing.

Thirty bores have been drilled to hard rock (2 to 39 m) for observations of the deeper aquifer in this catchment. Twenty two of these bores are placed on a 200 m square grid.

Only two of the deep bores did not intersect a permanent aquifer, and these bores, which were seasonally dry before clearing, are now permanently wet. In 1978 the head of water in one of these bores reached the top of the casing. The trend of the head of water in these, and several other bores within the catchment, is obscured by total saturation of the soil profile, and local groundwater discharge each winter.

Significant increases of head since clearing are apparent in the hydrographs of twenty three bores in this catchment. Rates of increase range up to 3.5 m *per annum*, with a median value of about 2 m *per annum*. Increasing heads have been observed in bores which show both very slow (heavily damped) seasonal response to rainfall, and others in which the response is almost instantaneous and ranges in amplitude up to ∿ 5 m.

There is no obvious trend since clearing in the head of water in five bores. One of these has been fully artesian (head above ground level) since 1974, while the seasonal response of two others suggests that they also intersect confined aquifers. One of the remaining bores is slightly outside of the cleared area. Since 1977 the head of water in this bore has increased at about 0.5 m *per annum*, but it is still below levels reached in 1974 and 1975. The remaining bore is well within the cleared area. In 1974 the head rose ∿ 12 m in this bore, and then fell by ∿ 10 m over the next 2½ years. Since September 1977 (the end of the first winter after clearing) water has risen a net 0.76 m in this bore, but the significance of this change is not easily assessed in view of the earlier behaviour.

Fig. 4 shows the hydrographs of 2 bores in Wights catchment.

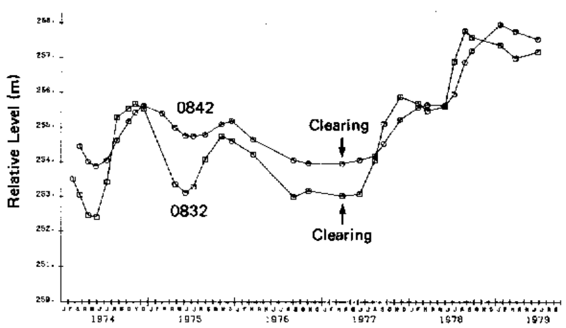

Fig. 4. Hydrograph records of two bores, Wights catchment.

Conclusions

Clearing has had no definite effect on the head of water in aquifers which develop seasonally in the more permeable near-surface material of lateritic profiles in the Darling Range. However, this aquifer may now develop more frequently, and hold water for a longer period of time than it did before clearing.

Where data are sufficient to indicate a trend after clearing, the head of water is increasing in 80 *per cent* of the bores which intersect permanent aquifers in the deeply weathered soils of the Darling Range. Water is rising in these bores at rates of around 0.8 m *per annum* in a 750 mm *per annum* rainfall zone, and 2 m *per annum* in a 1100 mm *per annum* zone. Since water levels have been falling for several years in 80 *per cent* of the bores examined for uncleared areas, it is likely that the effects of clearing have been underestimated in this analysis.