

**PRIME MINISTER'S SCIENCE, ENGINEERING AND INNOVATION  
COUNCIL**

**THIRD MEETING - 25 June 1999**

**AGENDA ITEM 2**

---

---

**MOVING FORWARD  
IN  
NATURAL RESOURCE MANAGEMENT**

**The contribution that  
science, engineering and innovation can make**

Presented by:  
The Honourable Mark Vaile  
Minister for Agriculture, Fisheries and Forestry

---

*The paper was prepared by the Natural Resource Management Scientific Advisory  
Group for the Minister for Agriculture, Fisheries and Forestry.*

# CONTENTS

	<b>Page</b>
<b>1. SUMMARY</b>	
<b>2. INTRODUCTION</b>	1
<b>3. OUR PROGRESS TO DATE</b>	2
<b>4. OUR CONTINUING PROBLEM</b>	4
4.1. The influence of human activity	4
4.2. The socio-economic dimension	4
4.3. Natural resource degradation and change in Australia	5
Waterlogging, sodicity and salinisation	5
Soil nutrient decline and acidification	7
Acid sulphate soils	8
Water and wind erosion	8
Soil structure decline associated with loss of organic carbon	9
Declining river, wetland and estuary health	9
Land and water contamination	10
Loss of ecosystem function and biodiversity	11
Weeds	11
Pests	12
Climate change	12
4.4. The extent of degradation	13
4.5. Why worry about continuing degradation?	14
<b>5. THE WAY FORWARD</b>	16
5.1. An interdisciplinary scientific approach to natural resource management	17
5.2. Increasing our understanding the state of our natural resources and evaluating the impacts of human activity	19
5.3. Managing natural resources at the appropriate scale	21
5.4. Developing innovative and sustainable production systems	22
5.5. Providing technological and innovative management solutions	26
5.6. Devising decision-support systems	26
5.7. Providing the factual basis for government and industry policies	28
Pricing natural resources	28
Production standards and accreditation	28
Eco-efficiency	30
5.8. Facilitating information exchange	30
<b>6. CONCLUDING MESSAGES</b>	33
<b>7. THE KEY OBSERVATIONS LISTED</b>	34
<b>8. RECOMMENDATIONS</b>	35
<b>9. ACKNOWLEDGEMENT</b>	36

## 1 SUMMARY

Caring for the soil, water, air, plants, animals and micro-organisms—our natural resources—continues to be a pressing concern for Australia. In the past decade or so we have made considerable advances in our understanding of natural resource management issues and of approaches to sustainable resource management.

Human activity since 1788 has again changed landscapes and the functioning of natural systems. Australia has greatly benefited economically and socially from this activity, but at some cost to our rural, urban, coastal and marine environments.

Continuing degradation is costing Australia dearly—in terms of lost production, the increased costs of production, the costs of rehabilitation, possible damage to a market advantage as a producer of ‘clean and green’ goods, increasing expenditure on building and repairing infrastructure, further biodiversity losses, the declining quality of air and water, and the declining aesthetic value of some of our landscapes.

We now have a greater understanding of these degradation problems, their causes, and new management approaches. We also know that degradation involves a complex interplay of biophysical factors and has economic and social causes, and that these factors must be considered together when developing new management approaches.

The Australian community expects the use and management of resources to be economically, environmentally and socially sound and sustainable. Meeting this expectation will involve altering the way we use and manage our natural resources so that ecosystem processes and functions are retained. Science, engineering, innovation, and the right signals to landholders are pivotal to this move towards sustainable management of our natural resources.

It is also important, in this regard that we look beyond individual problems—be they salinity, farm viability, or loss of native species. Considering all the natural resource aspects of a landscape together takes full account of the links within and between natural systems and the interplay of economic, social and biophysical factors involved in degradation and remediation.

The Prime Minister’s Science, Engineering and Innovation Council can play an important part in this by fostering and supporting science and engineering in developing new, sustainable land use and land management systems that will help us meet our environmental, economic and social goals.

## 2 INTRODUCTION

This review examines the contribution science can make to the management of Australia's natural resources—the soil, water, air, plants, animals and micro-organisms—so that they are maintained in such a way that they can contribute to national goals.

Many advances have been made in better understanding and managing natural resources, but a wide range of degradation problems persist in our landscapes. The sectoral causes of degradation are many, and rural, urban, coastal and marine environments are all affected. Particular attention is given here, however, to the agricultural sector's impact on the natural resource base in Australia.\*

Natural resource management poses unique challenges for government and policy makers because the managers and users of natural resources are highly dispersed—there are 200 000 landholders across the continent, for example—and there is a complex mix of public and private benefits involved. This calls for close partnership between landholders, industry, other natural resource managers, governments, and the wider Australian community.

This review builds on the report dealing with dryland salinity, which was considered by the Prime Minister's Science, Engineering and Innovation Council in December 1998. That report noted that salinity is part of the wider question of natural resource management across rural landscapes and that it needs to be viewed in the context of a variety of other aspects of natural resource management.

---

\* The term 'sustainable agriculture' used throughout this paper means agricultural practices and systems that maintain or improve the economic viability of agricultural production; the social viability and wellbeing of rural communities; the ecologically sustainable use and management of Australia's natural resource base, including biodiversity; and ecosystems that are influenced by agricultural activities.

### 3 OUR PROGRESS TO DATE

In the past decade or so we have made considerable progress in natural resource management.

Governments, industry, the scientific community and the community in general are much more aware of and responsive to problems associated with natural resources. And among natural resource managers, rural industries and the community there is a growing awareness that sound management is important to achieving the economic, environmental and social goals we have as a nation.

This awareness and heightened commitment have been stimulated by the National Landcare Program and the Natural Heritage Trust. These initiatives have taken stewardship and the landcare ethic beyond rural communities to urban dwellers. They have also generated a belief that sustainable natural resource use is important if we are to meet future needs and not undermine our ability to take advantage of new opportunities.

The focus on natural resource management has been reflected in increased scientific emphasis on the subject. Australia has a strong scientific institutional structure through the cooperative research centres, the research and development corporations, universities, CSIRO divisions and the Bureau of Rural Sciences, which are directing research into natural resource management.

The result of this research effort is a more sophisticated understanding of natural resource management. In particular, we now have a greater understanding of the complex environmental, economic and social interrelationships involved in landscape degradation and in management approaches. This constitutes a major step forward in understanding the causes of degradation, their on and off-site impacts and the human relationship with the environment.

A range of technological and scientific decision-support tools are being developed and beginning to be applied. There are techniques for measuring and monitoring soil and water quality and sophisticated models for assessing the impacts of land management; it is also possible to measure all sorts of features using satellite imagery and other forms of remote sensing.

With a better appreciation of the underlying causes of degradation and of natural systems' response to perturbations, science is in a position to help decision makers by providing the tools and understanding to assess the trade-offs involved in changing land use and land management practices. This can be at different levels: at the farm level by identifying the financial returns offered by particular farming practices and their impact on the natural resource base; and at the catchment and regional levels by communities determining the optimal level of investment to achieve specific outcomes for natural resource management.

Scale is also now being recognised as important in deciding how best to respond to degradation problems. Some problems can be tackled at the local and farm levels; others, because of their insidious and wide-ranging nature (such as dryland salinity), require treatment and policy responses by governments and the community at the larger catchment or regional level. More than ever before we realise that larger scale responses are needed.

As major natural resource managers and users, landholders have been increasing their understanding of sustainability and changing their land management practices and production technologies. For example, minimum tillage, stubble retention and drip irrigation are now widely used, and other methods such as precision farming and alley farming are emerging. The primary feature of these methods is a focus on developing farming systems more suited to our natural resources and, in particular, ones that are both profitable and sustainable in the longer term.

Increasingly, managers are educating themselves in sustainable production techniques, making use of both government and industry-based programs dealing with, for example, things such as business management and whole-farm planning.

Our investment in scientific research into natural resource management has been paying dividends. The innovative management approaches and technologies being developed and applied have the capacity not only to reduce the cost of degradation but also to allow the most suitable management choices to be made for the best production and environmental outcomes. A good example of the return on investment in research is the scientific work that led to the introduction of sub-surface irrigation in the vegetable sector. This resulted in a 60 per cent reduction in the amount of water used; a reduction in water passing into the water table and causing waterlogging problems; an increase in production and product quality; and, as a result, an increase in the value of the product.

But another result of the progress we have made is that we now know that dealing with natural resource degradation is difficult and will be a continuing process. There will not be a single, one-off solution: we are dealing with a dynamic natural system and a fluid social and economic environment. As opportunities and circumstances change, it is appropriate that management responses do too.

Accordingly, in managing modified environments for optimal outcomes for Australian society over time, a sustained scientific commitment is necessary.

<b>Key observations</b>	<p><b>We have made progress in managing our natural resources but we need to do more.</b></p> <p><b>Natural resource management is dynamic and complex; it requires sustained scientific commitment.</b></p>
-------------------------	--

## **4 OUR CONTINUING PROBLEM**

### **4.1 The influence of human activity**

Human activity affects the nature and rate of change of the natural resource base. Industry, human settlement and leisure pursuits all affect land, riverine and coastal and marine systems, the atmosphere (for example, air quality and greenhouse gas concentrations) and environmental values (for example, biodiversity) and amenities. Agriculture, which occupies on 60 per cent of Australia's land area and uses 70 per cent of delivered water supply, has changed rural landscapes and the way natural systems operate.

Meeting society's demands for food, fibre and manufactured goods results, however, in changes to natural systems. The sustainable use and management of our natural resource capital will ensure that we do not diminish our resources' capacity to meet society's future economic, environmental and social needs and respond to opportunities. The challenge, therefore, is to minimise the negative impacts of some human activities and continually work towards establishing sustainable wealth-generating systems.

Agriculture plays an important part in the Australian economy and society. In 1997–98 farm exports were worth \$25 billion, accounting for 23 per cent of exports of goods and services. About 380 000 people are employed in the industry, accounting for 4.5 per cent of total employment and in some regions up to 30 per cent of employment.

Inappropriate use and management of our natural resources has led to many different types of degradation. Past degradation and continued inappropriate practices reduce the potential benefits to be derived from our natural resources. Care of our land, water, air, living organisms and ecosystems is important to securing opportunities for, and the wellbeing of, all Australians.

The degradation of natural resources can affect people in different ways. For instance, the movement into water courses and groundwater of chemicals and other contaminants used in primary production, resource extraction and manufacturing processes is of growing concern. These contaminants will affect the quality, and thus usability, of the water supply.

Traditional approaches to natural resource management tended to look at the individual elements—soil, water, vegetation, and so on—as single entities. That is changing. Scientific evidence shows that viewing symptoms of natural resource degradation (such as those discussed in Section 4.3) in isolation is not the answer; rather, seeing them as components of the complex interactions between the soil, water and living organisms and as having a socio-economic dimension will achieve better and sustainable outcomes.

### **4.2 The socio-economic dimension**

Socio-economic factors—such as attitudes, age, education and skills levels, and financial position—strongly influence managers' decisions about production practices. Understanding the social and economic factors that give rise to degradation and that inhibit the adoption of best management practices will help us find more appropriate solutions. The best scientific and technical knowledge is useless if it is not used.

In this regard, a serious structural problem confronts Australia in seeking to develop sustainable agricultural systems. Many landholders in areas where degradation processes are very active—for example, in high-rainfall beef and sheep country—are ageing and have lower levels of education and skills, which militates against their adoption of new management practices or changes in land use. Given this age profile, it will probably be another five years before there is a significant turnover of farm ownership. Only then is it likely that new management systems and different production choices will be made or be influenced by a range of incentives and market signals.

The general level of education within broad age groups of landholders and farm managers is poor compared with that of managers in other sectors and small businesses. The situation is, however, improving: the proportion of 30–40 year old landholders with diplomas or degrees increased from 6.0 to 12.4 per cent between 1981 and 1991, and during the same period an increasing number of landholders aged less than 30 years gained certificate qualifications.

Landholders require an adequate level of income to enable them to invest in sustainable practices. Landholders in depressed industries (such as wool) or where the natural resource base has been adversely affected may have limited financial capacity to invest in new management approaches. The FM500 Group considers that a family needs to have over \$45 000 a year in disposable income from all sources to maintain its investment in the farm business as well as in environment protection. Yet the Australian Bureau of Agriculture and Resource Economics farm survey reveals that broadacre farms on the New South Wales tablelands generated an average of \$28 400 per farm per year in family income (that is, farm income plus off-farm income) between 1995 and 1998. The top-performing 25 per cent of these farms had an average family income of only \$40 300 a year.

### **4.3 Natural resource degradation and change in Australia**

The forms of natural degradation in Australia have been reported extensively; for example, in the 1996 state of the environment report and in the recently released report by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) on indicators of sustainable agriculture.

There are many forms of natural resource degradation, such as waterlogging, sodicity and salinisation; soil nutrient decline and acidification; acid sulphate soils; water and wind erosion; soil structure decline associated with loss of organic carbon; declining river, wetland and estuary health; loss of ecosystem function and biodiversity; soil and water contamination; weeds and pests. Climate change—including changes to rainfall and temperature—also affects natural resource management.

#### ***Waterlogging, sodicity and salinisation***

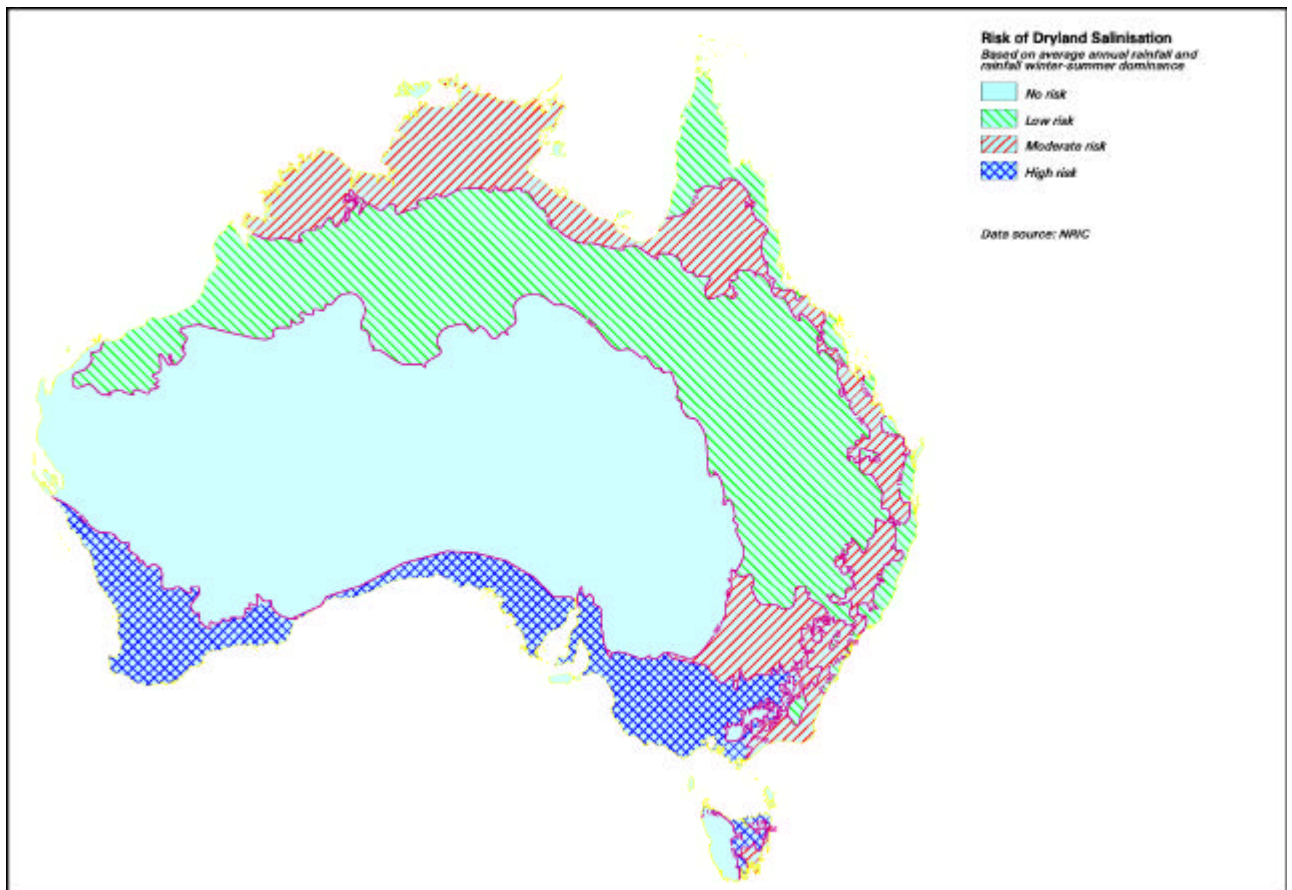
Australia is a dry and salty continent in which tree clearing has upset hydrological cycles, resulting in widespread and increasing dryland salinity. Waterlogging and increased soil sodicity may accompany salinisation. Sodicity occurs when the soil clays become saturated with sodium ions. This can lead to complete structural collapse, the plugging up of soil pores, impeded drainage, and consequent runoff and erosion. It can be accompanied by waterlogging on flat lands. Waterlogging and sodicity inhibit plant growth and may accelerate salinisation elsewhere or in the catchment. Naturally occurring sodic soils on farms can be treated by the application of gypsum.

Salinisation can be a result of both dryland and irrigation farming. The change from perennial native vegetation to annual crops and pastures allows more water to enter the ground and this

mobilises and relocates salt stored in the soil or in groundwater. Over decades or centuries water tables rise and break the land surface. Evaporation of soil water containing even small quantities of soluble salts leads to deposition of these salts on or near the soil surface. Salinisation can also occur in irrigated land where there is insufficient leaching and drainage, but dryland salinisation is Australia's most intractable land degradation threat. The report on dryland salinity that the Prime Minister's Science, Engineering and Innovation Council considered in December 1998 noted,

The time scales over which salinity establishes itself, spreads, and has its effects can be long, but once established it can be very difficult or impossible to contain or reverse. As a consequence salinity must inevitably continue to get worse in Australia as a result of land use decisions already made.

Recent scientific evidence suggests that the current area of about 2.5 million hectares of land affected by dryland salinity has the potential to increase to 12.5 million hectares (see Figure 1). The current area represents about 5 per cent of cultivated land; each year it is costing about \$130 million in lost agricultural production, \$100 million in damage to infrastructure, and at least \$40 million in loss of environmental assets. While Western Australia has the greatest area of land affected by dryland salinity at present (1.8 million hectares, with the potential to increase to 6.1 million hectares), New South Wales is of critical concern: it has the potential to reach 7.5 million hectares, much of which will endanger river and related ecological systems.



**Figure 1 Risk of dryland salinity in Australia**

Dryland salinity is also leading to increasing stream salinisation. Investigations by the Murray–Darling Basin Commission suggest that up to 75 per cent of salt loads in the major

Murray–Darling Basin streams are emanating from dryland catchments—not predominantly from irrigated catchments, as was previously thought. If we do not take action to redress this we will see a marked decline in the viability of much of the Murray–Darling Basin because the supply of potable water will be limited, with economic, social and environmental consequences.

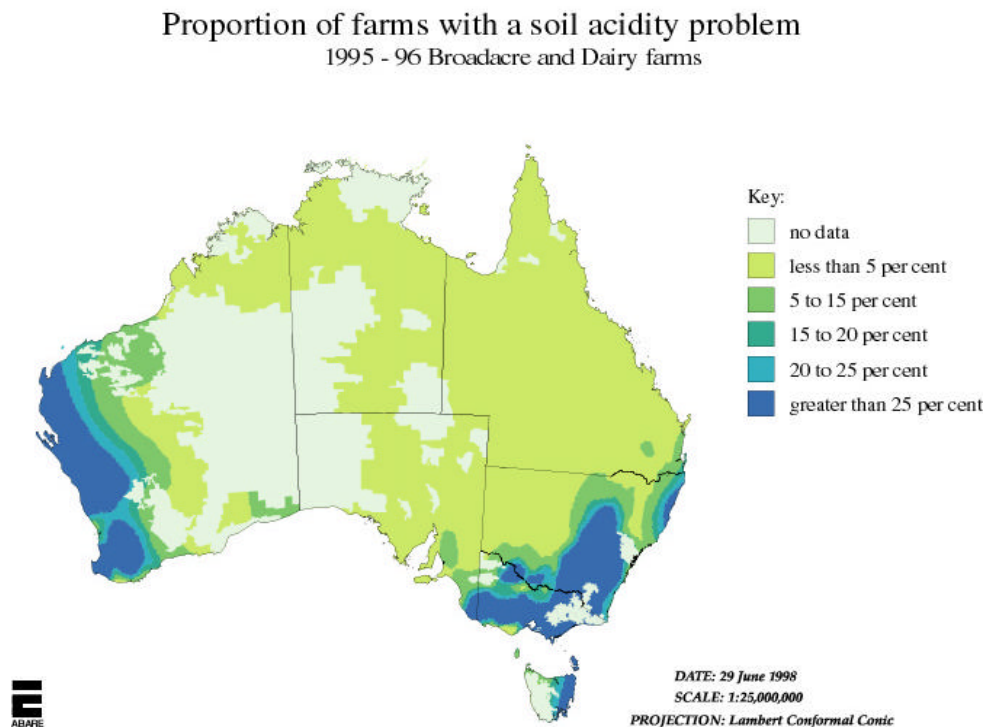
There are different ways of calculating and mapping the risk of salinisation. Figure 1 does this, but it is now thought it considerably underestimates the salinity hazard in northern and arid zones.

### ***Soil nutrient decline and acidification***

Many Australian soils are naturally low in phosphorus and trace elements compared with soils in other parts of the world. Native plants have adapted to these Australian soils, but they are deficient when it comes to the needs of introduced agricultural plants. The deficiencies have been overcome by the addition of fertiliser. In many regions, however, nutrient levels have declined as a result of harvesting and grazing, leaching below the root zone, and the erosion of topsoils.

The use of subterranean clover and other legumes has accelerated soil acidification and led to further depletion of soil fertility. Although the nitrogen-fixing process of legumes increases crop and pasture production, much of the nitrogen can be leached below the root zone, taking with it calcium, magnesium and potassium. These are then replaced with aluminium and hydrogen from clay minerals. The problem is that hydrogen lowers soil pH, aluminium is toxic to many crop and pasture species, and much of the nitrate leached from the root zone enters freshwater streams and underground water as a pollutant.

This process, known as ‘acidification’, affects a considerable area of agricultural production. Figure 2 shows the extent of acidic and potentially acidic soils in Australia that are both



**Figure 2**      **Soil acidification in Australia**

naturally occurring and accelerated through human activity. Acidification can also be caused by the application of acidifying fertilisers and by removal of alkaline products (such as lucerne hay) from paddocks.

Overall, about 24 million hectares of agricultural land is considered acidic. New South Wales has the largest area (9.5 million hectares), followed by Victoria (4.8 million hectares), Western Australia (4 million hectares), South Australia (2.8 million hectares), Queensland (2 million hectares) and Tasmania (1 million hectares). Much of this is naturally acidic. The soils of greatest concern are those that have undergone accelerated acidification: this includes much of the prime cropping and pastoral land of the high-rainfall zones and across semi-arid and humid tropical Australia. Major off-site problems arise particularly in the high-rainfall and recharge areas throughout the Murray–Darling Basin, where remediation is difficult and uneconomic. Similarly, acidification is one factor contributing to erosion and contamination in coastal regions of Queensland.

For Australia as a whole, production losses thought to be associated with acidification are estimated to exceed \$134 million a year, which represents about 17 per cent of estimated total production losses attributed to land degradation. In New South Wales the annual value of production lost as a result of acidification is estimated to exceed \$100 million.

The management solution to acidification on-farm—application of lime—is available. The returns on that investment can be high, so it is a matter of farm economics and farm management whether this problem is treated. It may be neither practical nor economic to apply lime. For example, returns may be poor for broadscale application or due to topography or highly variable rainfall. Use of lime treats the symptom only—it is the cause of acidification that needs to be addressed to avoid sub-soil acidification. Sub-soil acidification is very costly and difficult to treat and, in combination with surface acidity, can lead to a range of off-site impacts.

### ***Acid sulphate soils***

Acid sulphate soils and potentially acid sulphate soils occur extensively in low-lying coastal environments and in localised inland areas. Left below the water table, such soils are innocuous but when they are reclaimed by drainage for agriculture or urban development, if not managed properly they can release thousands of tonnes of sulphuric acid into the environment. This acidifies soils and is responsible for fish kills and other environmental damage in coastal waterways; it may also affect existing and potential infrastructure in coastal areas. Large amounts of acid can also be produced from mine waste dumps containing sulphites, the ‘active’ ingredient in acid sulphate soils where sulphite occurs in the form of iron pyrites.

It is scientifically and environmentally advisable to leave acid sulphate soils in their natural condition but this is not always possible. As a result, a number of methods have been developed to either neutralise acid generated as the pyrites oxidises, to keep the pyrites below the water table, where it will not oxidise, or, if costs are not a constraint, to physically remove the pyrites using hydrocyclones.

### ***Water and wind erosion***

Water erosion has damaged soils in all parts of Australia. Under natural conditions, processes of soil formation generate less than 1 tonne per hectare per year of new soil from rock and

erosion rates are often in the order of 0.2 tonnes per hectare per year. Many of our agricultural systems have doubled and tripled erosion rates and the sustainability of these systems on steeper slopes is obviously limited.

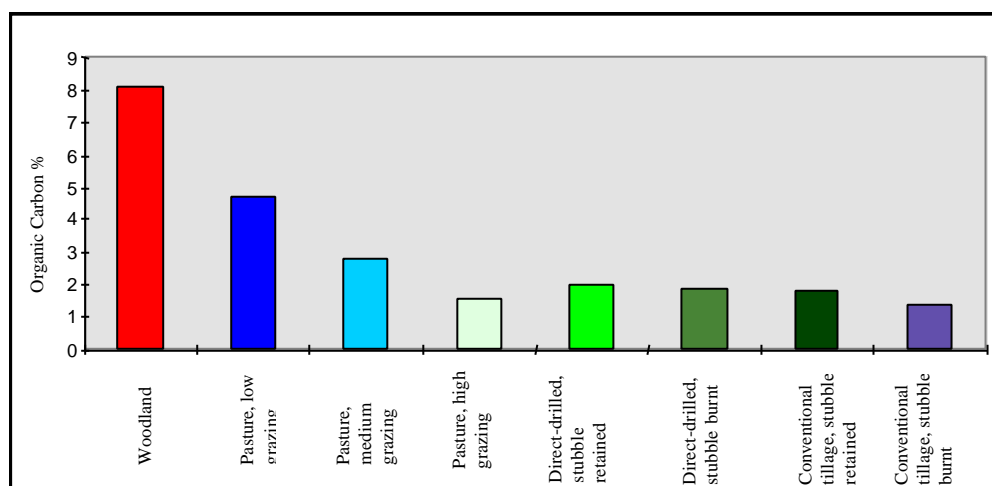
Wind erosion removes large amounts of fine topsoil and organic matter and associated nutrients from soil. The eroded dust contains 16 times more nitrogen and 11 times more organic matter than the soil from which it derives.

### ***Soil structure decline associated with loss of organic carbon***

Soil health depends on the maintenance of soil organic matter levels. Soil organic matter as a carbon supply is the energy ‘driver’ of the biological system. It is needed to increase the number and range of species of soil micro and macro fauna and flora. It provides energy and nutrients and the complexes for holding available nutrients, aids decontamination, stores water, and has a strong influence on soil structure and erosion protection.

High levels of organic matter in soils also help to achieve our greenhouse gas–abatement objectives: the carbon is stored in the soil and not released to the atmosphere. The increased organic matter sequesters carbon dioxide directly from the atmosphere and atmospheric carbon dioxide levels drop.

We know that the organic matter and carbon content of Australia’s soils can be restored and increased by changes in agricultural practices and soil-cultivating techniques. Figure 3 shows how our more intensive agricultural practices have reduced the carbon store in soils in south-eastern Australia. Science has developed a range of conservation-based farming techniques that can stabilise, and even improve, soil conditions, but adoption of these techniques has been sporadic.



**Figure 3** Organic carbon stores for various land use types

### ***Declining river, wetland and estuary health***

There is evidence of the deteriorating quality and environmental status of many of Australia’s rivers, particularly those along the eastern seaboard. Data from various sources show that in many regions up to one-third of rivers are in poor condition, another 40 per cent or more show signs of degradation, and relatively few are in good health.

The two main activities affecting the health of rivers, wetlands and estuaries are agricultural development and urban development. Various factors cause degradation:

- replacement of deep-rooted, perennial native vegetation with shallow-rooted crops and pastures;
- an increase in paved areas in urban and residential developments;
- unsealed roads and cropping on steep slopes;
- pollutants—sediment, mobilised salt, nutrients, agricultural chemicals and fecal material;
- pollutants—such as effluents—from urban and industrial areas;
- removal of riparian vegetation.

These factors contribute to river degradation by generating runoff, bank erosion, siltation on river beds, flood hazards, toxic algal blooms, fecal contamination, and to the decline in water quality through higher water salinity, turbidity and nutrient levels. There is a subsequent loss of recreational, cultural and environmental values, including the health of habitats.

The extraction of water for irrigation affects the flow regimes of rivers, wetlands and estuaries. The storage and distribution of water for irrigation have changed the flow regimes of our rivers. Winter runoff is stored in dams, resulting in a reduction in the frequency of high river flows. The water is released during periods of high water demand, when streams in their natural state would be in a low-flow condition. This hydrological distortion affects the ecological health of our river systems. An important water management question is the provision of environmental flows to improve the health of our rivers.

The effects of these changes to the rate and quality of river flow are also seen in our estuarine systems. Many east coast estuaries are increasingly experiencing algal blooms, declines in fish stocks, and habitat changes. Decreased river flows to estuaries cause intrusion of seawater further up the rivers, resulting in loss of riparian vegetation, bank erosion, and habitat changes. The high nutrient loads in flowing streams, coupled with decreased mixing as a result of low flows, provide good conditions for algal blooms. Filter feeders such as shellfish can become contaminated by pathogens from upstream, potentially affecting commercial enterprises.

Our groundwater resources are important and are often being inefficiently used or wasted through uncontrolled releases. Currently they provide 20 per cent of our total water requirements, and by area 60 per cent of Australia relies on groundwater. Recent investigations indicate that there is a considerable risk of many groundwaters becoming contaminated with effluent, industrial pollutants and agrochemicals. Furthermore, there is much less known about their sustainability than for our surface water supplies. Groundwater systems are generally strongly connected to surface processes and are a major component of the hydrological cycle.

### ***Land and water contamination***

Environmental contaminants constitute an emerging problem. They can come from point sources that are relatively easy to manage and control; for example, sewage and manufacturing discharges, and intensive livestock production facilities. Or they can come from diffuse sources that are more difficult to control in terms of potential offsite impacts; for example, broadacre fertiliser, pesticide and herbicide applications, and household discharges into stormwater drains and sewerage systems. The result for the environment and human

health is that there may be large amounts of organic, inorganic and heavy metal pollutants accumulating and moving across landscapes and into our water.

Increasing public awareness and the demand for safe, healthy food, a clean environment and high production standards mean that environmental contaminants will be of concern for the management of our production enterprises.

### ***Loss of ecosystem function and biodiversity***

Biodiversity is the variety of all life forms and their interactions within the ecosystem, and it has genetic, species, and ecosystem dimensions.

Many organisms that are vital to healthy ecosystems are minute and live in soil. For example, every hectare of soil in temperate regions contains about 20 000 kilograms of microscopic organisms (such as bacteria and fungi); 50 kilograms of microfauna (organisms less than 2 millimetres long, such as nematodes and protozoa); 20 kilograms of slightly larger organisms (2–10 millimetres long, such as microarthropods); and 900 kilograms of organisms greater than 10 millimetres long (such as earthworms and termites). These organisms contribute to soil fertility and agricultural productivity but are threatened by some agricultural practices and stimulated by others.

Ecosystem processes and functions—such as soil formation, nutrient cycling, the maintenance of hydrological cycles, natural predation (for example, of insect pests), greenhouse gas sequestration and pollination of crops—are ‘services’ upon which the sustainability of natural resource use depends. In addition, Australian biodiversity has important economic values: many are yet to be realised, particularly in the food, biotechnology and pharmaceutical industries. As biodiversity is lost, ecosystems become less complex and less resilient to dramatic change such as drought and fire. This may result in a decline in ecosystem performance and affect the capacity to deliver ecosystem services. This has economic consequences, including the opportunity cost of lost genetic material.

The loss of ecosystems, species and habitat is therefore a serious problem. The greatest changes have occurred in Australia’s agricultural zones and urban areas. In many areas, less than 10 per cent of the original vegetation remains. The loss of native vegetation has impacts on ecosystem functioning in many parts of Australia. The hydrologic balance of the agricultural zones has been changed. Vegetation clearing generates greenhouse gas emissions and reduces soil condition and carbon. It has also led to changes in surface flow of wind and water, and this has increased the severity of their degradation impact.

### ***Weeds***

Weeds are a serious threat to Australia’s primary production and natural environment. There is evidence of increasing weed encroachment in or into almost all ecosystems of immediate economic and conservation value in Australia.

About half of the more than 1900 species of vascular plant introduced to Australia since European settlement are now regarded as weeds; more than 220 of them have been declared noxious weeds. Native species can also become weeds if, as a result of human disturbance, they become established in regions outside their natural habitat or they increase in abundance.

Weeds impose a high cost on agriculture through reduced crop and pasture yields, the poisoning of stock, the presence of vegetable matter in wool and goat fibres, tainted products, carcass damage and animal stress resulting from physical discomfort, and the cost of herbicides for weed treatment.

### *Pests*

A number of introduced animals—rabbits, foxes, feral goats and pigs, for example—and some native animals have established large and widespread populations in Australia and are having deleterious effects on agricultural production and conservation values.

It is difficult to estimate the economic costs posed by pest species. For example, the rabbit—our most destructive vertebrate pest—is estimated to cost Australian primary industry between \$90 million and \$600 million a year, depending on what is costed.

In terms of abundance and diversity, insects dominate terrestrial ecosystems and play a vital role in maintaining ecosystems. Using pesticides to control insects that impinge on human activity can have unintended effects on other natural resources. Careless or inappropriate application of pesticides can harm beneficial insects and other invertebrates, such as earthworms and dung beetles. Their destruction can affect soils by preventing the retention of dung-related nutrients, by allowing nutrients to be ‘leaked’ from farms, and by limiting worms’ ability to enrich soils.

### *Climate change*

CSIRO research findings suggest that in the next 30 years parts of inland northern Australia and the coastal areas will warm by 0.4–1.4 C and that there will be heavier rainfall events in northern and central Australia.

Changes in rainfall and temperature would lead to, among other things, different regional rainfall patterns; more severe and frequent storm events; the need to develop better erosion-control measures and re-design water storage, irrigation and drainage systems; changed cropping patterns and geographical locations suitable for individual crops; and the spread of pest and diseases. Consideration of the potential for climate change will play an increasing part in decision making, particularly at the regional level. Better vegetation and soil management offers big gains for biodiversity, soil carbon and productivity.

<b>Key observations</b>	<b>Natural resource degradation and change constitute a continuing and serious problem for Australia.</b>
	<b>The factors that cause degradation are interrelated, and degradation problems should not be viewed in isolation; they should be viewed from a ‘whole-of-landscape’ perspective.</b>

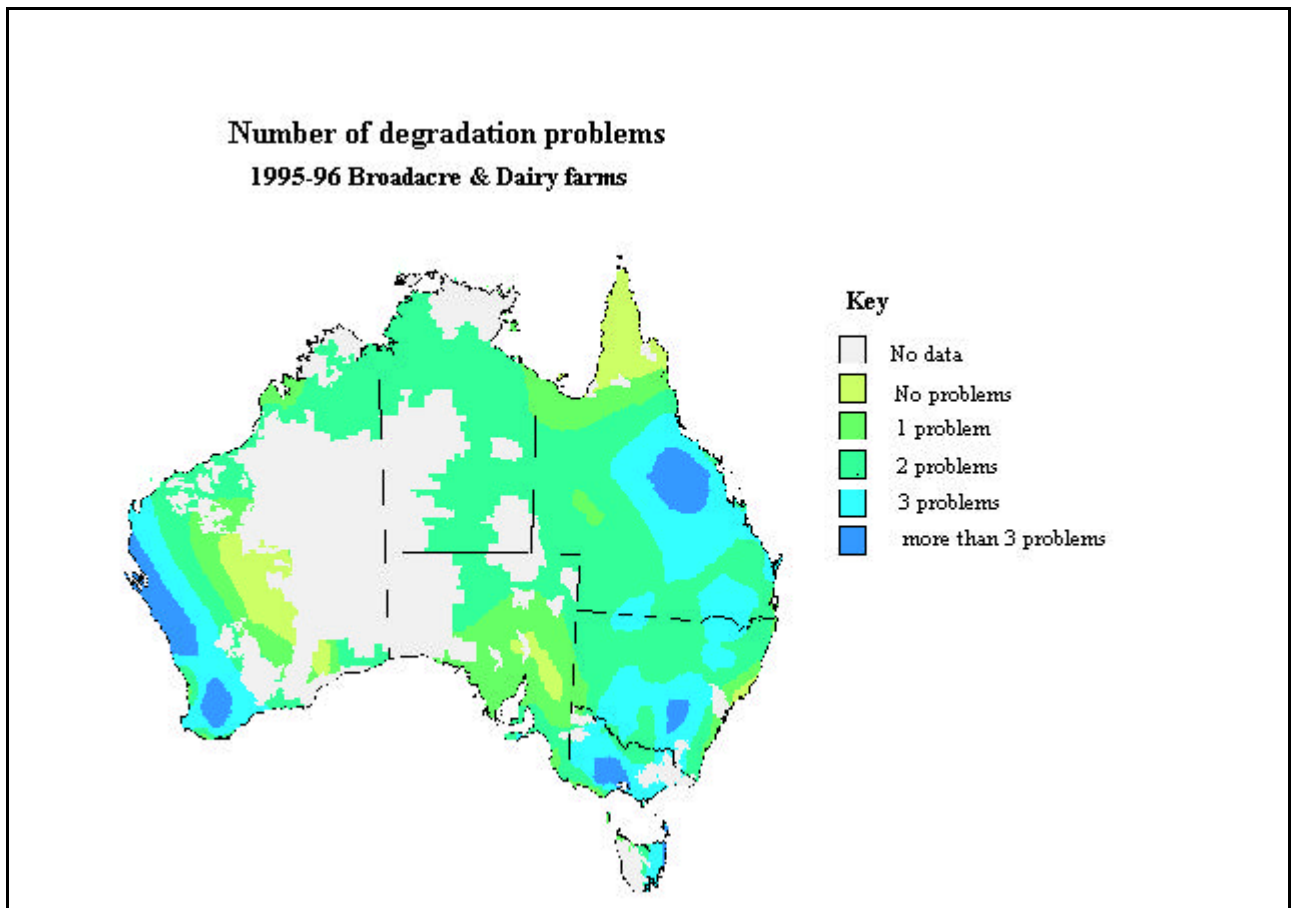
#### 4.4 The extent of degradation

Table 1 shows that a high proportion of our agricultural land is or will be in the relatively short term (the next 50 years) affected by at least one form of land degradation. Many of these forms of degradation—among them salinisation and acidification—are quite insidious, having thresholds beyond which there is ecosystem collapse.

**Table 1** Degradation and potential degradation in Australia, by degradation type  
(million hectares)

Degradation type	Estimated area degraded or at risk
Soil structure decline/compaction	12.3–55.0
Water repellence	1.1–7.0
Water erosion	52.5–181.0
Wind erosion	90.0 (at risk)
Soil acidification	43.0 (at risk)
Soil fertility decline/organic matter loss	3.0–10.0
Dryland salinisation	2.5–12.5

It is also the case that degradation problems occur together in the landscape. This reflects the interrelationship that often exists between different forms of degradation. Figure 4 shows the perceptions of Australian broadacre and dairy farmers about land degradation issues in their local area: landholders themselves perceive a multiplicity of problems.



**Figure 4** Perceived number of degradation problems

Table 2 gives examples of the different forms of land degradation that occur together in some regions.

**Table 2      Some regions with multiple forms of land degradation**

<b>Region</b>	<b>Degradation problems</b>
South-eastern Australian wheat–sheep belt, Western Australian wheat–sheep belt	Soil structure decline, acidification, salinisation risk, biodiversity loss
Basalt soils in Tasmania, south–central Queensland and elsewhere	Soil structure decline, water erosion
East coast of Australia	Environmental contamination, acid sulphate soils, loss of wetlands, declining water quality in streams and estuaries with increasing land- use pressures, groundwater contamination
Western Australian wheatbelt	Widespread land and stream salinisation, soil acidification, wind erosion

The occurrence of multiple forms of land degradation in a region has implications for the strategic targeting of actions. Dealing with these problems together, although they are complex and difficult, can achieve better outcomes. Sound responses will rely on an understanding of the interrelationships and causes of the multitude of degradation problems, their social, economic and environmental impacts, and an assessment of how and where private and public funding would offer the most efficient and effective outcomes.

#### **4.5 Why worry about continuing degradation?**

Production, environmental and social concerns (including intergenerational equity) make it imperative that action is taken to prevent and reverse the continuing degradation of our natural resource base. If not, there may be serious consequences:

- further biodiversity loss;
- more costly losses to agricultural production;
- damage to our market advantage as a producer of ‘clean and green’ goods;
- increasing expenditure to remedy problems such as river salinisation and infrastructure damage caused by salt, wind erosion, sedimentation of dams, and so on;
- the limiting of our ability to benefit from advances in research and technology;
- a gradual diminution in the aesthetic and economic value of our landscapes and attractions, which will adversely affect eco-tourism;
- increased greenhouse gas emissions as a result of land clearing and the loss of soil carbon.

There are four main imperatives for change.

- The Australian community is becoming increasingly aware of, and concerned about, the extent and severity of degradation of our natural resources and its impact (including the loss of biodiversity and the higher costs to infrastructure) and is demanding environmentally sound production and manufacturing practices.
- Many of our trading partners are developing a preference for food, fibre and timber that are produced in an environmentally friendly way.

- There is a growing realisation that ecologically sustainable development offers benefits not only in terms of the quality of the environment and life but also in terms of long-term business viability and thus profit.
- Resource degradation may reduce opportunities for eco-related business, including tourism.

To date we have not been able to put a value on the total cost of degradation to the economy, environment and society. But we are extending our knowledge about the extent of degradation. The National Land and Water Resources Audit is collating a national-scale baseline set of information on the degradation of our soil, water and vegetation resources: this will help us determine the real extent of annual losses.

In terms of agricultural production alone, it was estimated in 1991 that losses resulting from erosion, acidification, salinisation, soil structure decline, water-repellent soils and shrub invasion amounted to approximately \$1 billion a year in current prices. The yield reduction resulting from soil nutrient decline is estimated to amount to over \$300 million annually in north-eastern Australia. The use of gypsum to alleviate soil sodicity in wheat and barley cropping areas in Victoria and South Australia was assessed to give a net present value of \$149 million to landholders.

In terms of nutrient replacement, it has been estimated that the 1983 Melbourne dust cloud, which followed severe wind-induced erosion in north-western Victoria and South Australia, led to the loss of \$3.9 million worth of nitrate and \$0.4 million worth of phosphorus in terms of replacing these nutrients lost to the eroded soils. Similarly, it has been estimated that a one-hour bout of wind erosion in South Australia can cost about \$12 a hectare in lost nutrients.

The competitiveness of Australian products may also suffer from domestic and international consumers' concerns about product integrity (safety) and the sustainability of production systems. On the other hand, our competitive advantage would be increased if we had an image as a producer of safe, healthy goods that are produced using sound natural resource management practices. Government requires precisely this image for Australian agriculture, to facilitate the 'Supermarket to Asia' program.

Many of the threats to our natural resources will ultimately have consequences for the nation's infrastructure.

- Rising saline groundwater affects roads, bridges, pipelines, electricity distribution systems, the footings of buildings and many other infrastructure elements.
- Loss of soil structure leads to increased runoff and consequently more severe flooding, with associated increases in damage to property and infrastructure.
- Loss of wetlands leads to increased flooding, reduced water quality, and reduced biodiversity.
- Increased runoff carries contaminants that add to the cost of water treatment.
- Soil acidification can lead to increased leaching of humic substances, which decreases soil productivity and increases the cost of water treatment.
- Clarifying domestic and industrial water to eliminate turbidity resulting from sodicity is costly.

The overall costs of environmental degradation in terms of its effects on infrastructure have not been extensively studied and can be difficult to quantify, but estimates have been

developed for some specific cases. A recent Australian Bureau of Agriculture and Resource Economics report estimates for south-western New South Wales that 34 per cent of state roads and 21 per cent of national highways are affected by high watertables, costing \$9 million a year. Studies in Western Australia show that maintenance and reconstruction costs for roads are likely to amount to \$50–100 million in the next 20 years. In the Loddon–Campaspe region in Victoria, 64 per cent of local government, state and federal government and public utility costs attributable to salinity and high watertables (\$4.2 million a year) were associated with infrastructure (repairs, maintenance and capital works). In addition, the costs of treating water from catchments of deteriorating quality are high.

There is also evidence that adoption of sound natural resource management practices can result in big savings to the community by obviating or reducing infrastructure costs. In an independent economic analysis of options for securing a continuing supply of potable water from the Tarago catchment in Victoria, benefits of between 2.2:1 and 4:1 were calculated for integrated management of land uses by applying ‘best management’ practices compared with conventional water treatment.

As we begin to quantify the costs of degradation to infrastructure, along with the other important impacts, the economic benefits of early and decisive action to arrest, reverse and prevent degradation become evident.

Reduced river flows, increased flood frequency, declining biodiversity, declining eco-tourism, and visible signs of land degradation (gullies, dead trees, salt pans, and so on)—which limit people’s appreciation of the environment and rural landscapes—are other costs. Greater risks to people’s health—as a consequence of poor water quality in urban areas, for example—are also a growing concern.

Degradation therefore costs Australia perhaps billions of dollars each year. This equates to a significant proportion of the gross value of agricultural production and, considering the seriousness of the resultant effects on cities, industry, infrastructure and tourism, we cannot be idle.

Finding solutions will involve a concerted effort by government, industry and the community to ensure that our natural resources can meet our future needs and be capable of responding to opportunities. The extent and rate of continuing degradation requires it.

<b>Key observation</b>	<b>The extent and rate of continuing degradation require that we continue to search for new approaches to ensure that our natural resources are managed and used in a sustainable way.</b>
------------------------	--

## 5 THE WAY FORWARD

Ecologically sustainable development involves using and managing our natural resources in a way that does not diminish the resources' capacity to meet society's economic, environmental and social needs.

Achieving sustainable development and management of our natural resources entails a partnership—between individuals, the community, industry and government and spanning policy, research and management. The work of our scientific institutions is an important element in this mix, since decisions made, at all levels, about natural resource management must be based on sound scientific research, information and advice. It is vital that research focuses on providing practical policy and management responses.

Human-induced changes to the state of our natural resource base are inevitable, but the adoption of management practices and production systems that are more in tune with natural processes will achieve more sustainable outcomes. This will involve more sophisticated and innovative ways of responding to current degradation problems and encouraging natural resource managers to adopt better practices. Anticipating future problems is just as important so that we are in a position to research and develop the solutions now.

This will require new scientific approaches and new policy directions—taking a holistic approach to the management of landscapes. It will also require natural resource managers to be more flexible and innovative in adopting new technologies and management practices.

Science is central to sustainable management of natural resources. It can assist in a variety of ways:

- taking an interdisciplinary scientific approach to natural resource management;
- increasing our understanding of the state of our natural resources and evaluating the impacts of human activity;
- supporting natural resource management at the appropriate scale;
- developing innovative and sustainable production systems;
- providing technological and innovative management solutions;
- devising decision-support systems;
- providing the factual basis for government and industry policies, including market-based incentives;
- facilitating information exchange between the science community and natural resource managers.

### 5.1 An interdisciplinary scientific approach to natural resource management

In seeking greater understanding of the natural resource system, science must continue to move towards a holistic approach—one that looks beyond individual components to their interrelationships, the processes within the system as a whole, and the factors that influence the functioning of that system. Only through an integrated systems approach will we come to understand how natural systems work and the interplay between ecosystems, economic and social influences.

Industry-based research organisations, government agencies and research organisations, catchment management authorities and rural communities are cooperating in their efforts to learn more about degradation problems and to plan and implement strategies for remediation and sustainable management. Past institutional research structures have created a widespread reductionist, single-problem approach to research. An interdisciplinary approach to scientific research and development is needed, bringing together expertise from the social sciences, the biophysical sciences, economics, industry, land management and supporting services. There is also a role for researchers to anticipate future problems and seek to develop solutions that offer benefits for the present and the future.

Implementing interdisciplinary research provides a major institutional challenge for Australia. There are both public and private benefits from research into natural resource management. This suggests that industry would benefit from taking a greater role in research and development in the natural resource management field. Partnerships for interdisciplinary research, for example, can be led by industry through industry-based research and development corporations.

The Cooperative Research Centre program is an example of where interdisciplinary research can work well—taking a collaborative, interdisciplinary approach to research and development and linking public sector and higher education research organisations with practitioners from the public and private sector. This approach encourages greater industry involvement in guiding research and development in the public sector.

Box 1 illustrates the value of a collaborative, interdisciplinary approach to scientific research that seeks to change the behaviour of natural resource managers and so achieve better management outcomes. Clearly, there are benefits to be derived from encouraging and facilitating the adoption of such approaches.

Although scientific approaches that integrate social, economic and environmental factors are fundamental to our understanding of the causes of degradation and to the development of new production systems, there is a question whether we have the scientific capacity—the knowledge, expertise and institutional arrangements—to adopt such approaches. Social research into natural resource decision making, for example, is being done but it is a relatively new research area.

Ensuring that our institutional framework fosters interdisciplinary approaches is also important—drawing upon the expertise of social scientists, biophysical scientists, economists, people in industry, land managers and supporting service providers. This can be done in a number of ways, among them the following:

- funding arrangements that facilitate interdisciplinary action (including industry funding);
- re-thinking institutional arrangements—coalitions, alliances, partnerships, and so on—to facilitate interdisciplinary action;
- encouraging participatory approaches to production system research that involves natural resource managers, the community and relevant institutions;
- adopting systems approaches to science that offer optimum results for natural resource management, sustainability, productivity and profitability.

<b>Key observation</b>	<b>The scientific research effort needs to be interdisciplinary, using collaborative mechanisms that</b>
------------------------	--

*The paper was prepared by the Natural Resource Management Scientific Advisory Group for the Minister for Agriculture, Fisheries and Forestry.*

**take account of the social, economic and environmental aspects of natural resource management.**

**Box 1 Interdisciplinary research: pesticides and the cotton industry**

In 1992 the Australian cotton industry was facing stringent environmental regulation without the supporting scientific knowledge. Increasing evidence that some fish kills were associated with the industry's use of pesticides had led to proposals to ban certain pesticides and/or to require growers to reconfigure their farms so as to capture, where this was not already done, the runoff from storms. (It was thought that storm runoff was the main way in which pesticides attached to soil particles and reached creeks and rivers.)

The cost to the industry of these proposals would have run into many millions of dollars annually, threatening the industry's viability as a mainstay of regional employment and economies.

In response to the situation, the Cotton Research and Development Corporation, the Land and Water Resources Research and Development Corporation and the Murray–Darling Basin Commission established an integrated R&D program to study all aspects of pesticide transport, deposition and biological impacts. The purpose was to provide a firm basis of knowledge from which to design management practices that would maintain the industry's economic contribution while avoiding environmental contamination. The five-year program cost \$7.3 million. Its interdisciplinary approach, involving 50 researchers from 12 organisations, was considered highly successful. Integration of the science and the management and regulatory contexts meant that the program is widely regarded as a world first for pesticide R&D. The industry–government partnership and the involvement of regulatory agencies from the outset made an important contribution to changing industry practices.

We now know what happens, quantitatively, to the pesticide from the moment it leaves the spray nozzle until it ultimately degrades to harmless products. This knowledge was used to develop a comprehensive set of 'best management' practices, which have been widely adopted following two years of testing and training. Regulatory agencies have also adopted these best management practices as the standards that all growers are required to meet for continued pesticide use. The industry and agencies are now developing an audit program to assess compliance.

The program has been independently assessed as having a national benefit:cost ratio of at least 20:1. The involvement of all interested parties and the commissioning of an integrated and multi-faceted set of R&D projects were the keys to success and point to the way forward for research into the management of natural resources.

**5.2 Increasing our understanding of the state of our natural resources and evaluating the impacts of human activity**

The availability of sound data and information on the condition of the natural resource base, over both space and time, underpins the development of sound policies and programs, innovative farming and production systems, and better management approaches. It is also important in monitoring and evaluating the condition of natural resources to provide feedback to managers and policy makers.

The National Land and Water Resources Audit will provide valuable baseline data sets for monitoring changes in natural resource condition and for charting catchment and regional

land use impacts. It will assemble existing data sets and identify gaps in our knowledge; then we will be able to identify priority areas for research and development. It will also provide information on which to base future decisions about policy directions and priorities for program funding.

To augment the knowledge gained through the National Land and Water Resources Audit and the state of the environment reporting process, it is appropriate for research institutions and other bodies to focus on obtaining reliable, extensive and consistent data on the condition of and trends in our natural resources at local, catchment, regional and national scales. Making this data and information readily accessible in a useable form would increase the availability of knowledge of different land types, their distribution and biophysical resources. It is also necessary that attention be given to increasing our understanding of the interrelationships between these biophysical characteristics and their properties, which together determine the functioning of the nutrient and hydrological cycles of the natural system. This would help people plan, use and manage the natural resource base within its capabilities.

Collecting and processing data are expensive, and it is important that the benefits of having additional data are weighed against the costs. Initiatives such as the National Land and Water Resources Audit can help in this regard by providing nationally consistent approaches to data collection and storage.

The collection and analysis of data on the condition of and trends in natural resources at the various scales need not be the task solely of research institutions. It is appropriate that this be supported through collaborative activity by research institutions, government agencies, local and regional authorities, and private sector information providers. Community groups and landholders now have the ability to supplement soil and water analysis at the local and on-farm levels as a result of technological advances. This would be useful to support the development of their regional strategies and whole-farm plans. This would be facilitated by improving the skills and capacity of local and regional communities and landholders in data collection and analysis.

The development of desktop computer-based geographic information systems for use by natural resource managers improves the capacity to make informed decisions. Access to information and data by managers is available through the Internet—with processing of specific information requests done remotely and then sent through the Internet to the desktop in a useable form, such as a map or image. The products are relatively inexpensive and make access by rural and remote communities simple and feasible.

Maintaining the integrity and relevance of data is important: this can place a constraint on community groups and landholders contributing to central databases. Nonetheless, data collected at the local level can be important to on-farm and regional decision making.

<b>Key observation</b>	<b>Data on the condition of and trends in our natural resources—at farm, local, catchment, regional and national scales—need to be assembled on a continuing basis and to be readily accessible in a useable form. Cost-effectiveness should be an important criterion for data collection.</b>
------------------------	---

We will never have complete knowledge of how the natural system operates. Adaptive management offers a practical approach to this problem. An important element of this is the

---

*The paper was prepared by the Natural Resource Management Scientific Advisory Group for the Minister for Agriculture, Fisheries and Forestry.*

feedback of information so as to monitor responses to management prescriptions and then make adjustments to management practices. Adaptive management relies on sound baseline information and continued monitoring of production and management impacts. At the farm level, many people are now collecting and analysing data on natural resources with a view to improving productivity and profitability. A presentation to the 1999 ABARE Outlook Conference demonstrated how one landholder's monitoring of soil nutrients and water and management of rotations had improved sustainability in terms of soil organic matter, structure, water use, effectiveness and profitability.

Adaptive management techniques applied across catchments and regions can also contribute substantially to improved outcomes. It has recently been predicted that an adaptive management policy for the Murray–Darling Basin could double the economic output over 25 years from the same volume of water delivered for irrigation.

<b>Key observations</b>	<p><b>Local and regional community groups and landholders should be trained in data collection and analysis techniques to assist in developing regional strategies and whole-farm plans.</b></p> <p><b>Adaptive management approaches—a practical response to the lack of knowledge about appropriate natural resource management practices—should be encouraged.</b></p>
-------------------------	---

### 5.3 Managing natural resources at the appropriate scale

The interrelationships between environmental, social and economic processes that influence natural resource management operate at various scales. More than ever before, we realise that some aspects of natural resource management are best dealt with at larger scales. Some problems, such as dryland salinity and acidification are insidious, extending over large areas and are therefore beyond the capability of individual landholders to rectify. Projects that deal with the causes of degradation at the catchment or regional level can offer the best outcomes.

Decisions about the most 'appropriate' scale at which to tackle natural resource problems should be based on scientific information and data—environmental, social and economic—compiled at the relevant scale, be that farm, local, catchment, regional or national.

At the policy level, there has been a trend towards establishing institutional structures to support larger scale approaches to resource management—such as catchment management authorities and regional planning processes. But there are serious knowledge gaps when we try to work at these scales.

The search for solutions is going to be scientifically demanding. There are inevitable trade-off decisions in choosing solutions at larger scales—such as whether to intervene or maintain the status quo. These decisions need to be well informed by science and have the confidence of rural communities. In this regard, science has a role in improving predictive capacity for decision makers. All this requires new ways of working within the economic and social frameworks of rural communities.

<b>Key observation</b>	<p><b>The development of management approaches at the appropriate scale—including regional-scale projects—</b></p>
------------------------	--

**should be based on sound scientific knowledge and advice.**

#### **5.4 Developing innovative and sustainable production systems**

Agriculture continues to play a very important part in Australia's economy and society and as an industry, it continues to grow: farm gross product has risen by 50 per cent in real terms in the last 25 years. Productivity also continues to increase, at around 3 per cent a year, reflecting in part a solid scientific and technological base. Significant growth in productivity has been achieved through, for example, scientific development of new plant varieties, new animal husbandry techniques, and chemical and pesticide advances. This increase in productivity has, however, masked the impact of agricultural practices on our natural resource base. It is arguable that production increases would be higher if it were not for the impact degradation has in reducing yield.

Australian rural production systems were developed by changing the nature of and seasonal patterns in the hydrological and nutrient cycles. The result is that many current production systems 'leak' water and nutrients beyond the root zone and release increased amounts of water, nutrients, sediment and contaminants into rivers and waterways. It is these changes to natural systems that are central to much of the natural resource degradation that confronts us.

Understanding ecosystem processes at the landscape scale will enable us to design production systems more in tune with natural processes (see Box 2).

Although landholders and rural communities can do much to work towards more sustainable practices, research consistently demonstrates that radical land use change is required over large areas to reduce the rise of water tables, waterlogging and salinisation. Field experiments coordinated across Australia, using calibrated simulation modelling, show that our farming systems for large areas of the agricultural zone are incapable of minimising salinisation, acidification and the decline of soil carbon while at the same time providing adequate farm income.

<b>Key observation</b>	<b>Australian production systems need to be more in tune with natural processes and to operate within the capacity of the natural resource base.</b>
------------------------	--

There is a role for science in developing 'true blue' production systems that are better suited to our natural resources and unique ecosystems. In the case of agriculture, these production systems will mimic ecosystem functions and reduce leakage, and they will be profitable and sustainable.

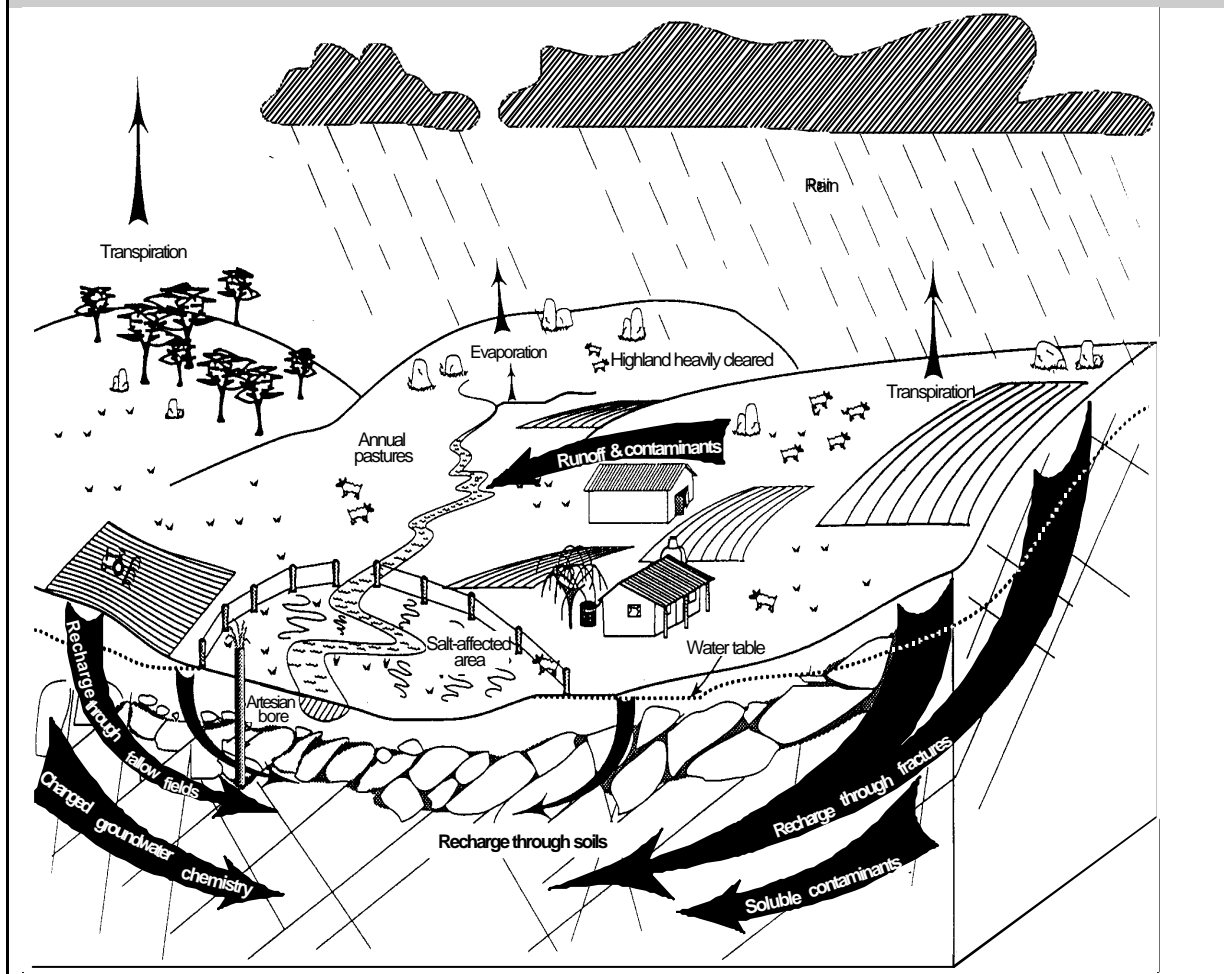
Production systems that minimise leakage can reduce off-site impacts and offer production benefits. For example, the dairy industry and local natural resource management agencies in south-eastern Victoria are seeking to reduce the leakage of phosphorus from the Macalister Irrigation District by 40 per cent by 2005. The recycling of nutrients on the dairy farms will ensure that the phosphorous is kept on the farm to grow grass and contribute to farm production and also reduce the level of nutrient flows into waterways, thus reducing algal blooms in the Gippsland Lakes.

## Box 2 Landscape processes

Soil, water, vegetation and biological interactions that are important to sustainable management of land and water operate at many space and time scales in the landscape. These need to be understood at the paddock, hillslope, catchment and regional levels and over differing time scales if we are to achieve sustainable agriculture and natural resource management.

The impact of landscape processes is evident in the rates and magnitude of the storage, transport and transformation of chemicals and sediments in the landscape, which influence the form and nature of streams, lakes, reservoirs and wetlands. The catchment water balance is strongly influenced by changes in these rates and magnitudes and is evident in changes to stream flow, groundwater flow, and the mobilisation of salt and other solutes in the landscape. For instance, changing the partitioning of rainfall between runoff, deep drainage and evapotranspiration directly determines the slope and position of the water table in the landscape, with profound consequences for the nature of chemicals released to the landscape and the ions mobilised to and within springs, rivers and wetlands. This in turn is reflected in the larger scale hydrogeology and geochemistry of the landscape.

Agricultural systems must be in sympathy with how natural ecosystems capture, use and dispose of water and nutrients, at the landscape level. Sustainable farming must also be able to make better use of the soil processes of decomposition, transformation and storage. Fostering and managing soil processes that deal with organic and inorganic inputs of fertilisers, pesticides, and associated contaminants and residuals are central to the development of more sustainable farming systems.



Scientific research has already identified a range of new management techniques that can help in reducing adverse impacts on the natural resource base while increasing productivity. Examples are minimum tillage, cell grazing, better management of wastes in the dairy industry, and drip irrigation, all of which are now widely practised. Other, more innovative systems such as precision farming (see Box 3) and alley farming are also emerging.

### **Box 3 Precision farming**

A small but increasing number of Australian landholders are adopting 'precision farming' techniques. These techniques aim to reduce costs, increase yields and minimise off-site impacts by allowing specific areas within a paddock to be treated differently and given the attention necessary to improve yields. This is in contrast to conventional agriculture, which treats paddocks as homogeneous units, with inputs applied at the same rate across the entire paddock. Precision farming also allows farmers to redesign their farm layout to take advantage of the particular characteristics of their land and to adapt farm plans to land capabilities.

Precision farming is technology and information intensive. It involves the collection of data on crop yield and quality by instruments on machinery linked to a global positioning system. This identifies the different yields across the paddock. It also involves analysing soil profiles (structure, moisture and nutrients) and other reasons for yield variation (for example, weeds) across the paddock. Combining this information to generate maps that identify yield variability, topography, soils, weeds, etc allows machinery to be site specific in applying inputs (seeding, spraying, liming, fertilisers) relevant to the variability across the paddock.

Landholders need to take a long term view when considering adopting precision farming. Yield monitoring set-up costs can be up to \$20,000, with additional costs for the variable rate technology necessary to deliver the farming inputs.

It is difficult to predict the expected returns to a farm enterprise of implementing precision farming. Overseas experience is now showing that precision farming does increase profitability. Nevertheless, it is not suitable for every farm. The potential returns will vary between and within farms, depending on the value of the crop, the variability to be managed, the success of techniques, and the costs.

In Australia, precision farming has mainly been adopted in the broadacre, sugar and rice industries. Some pastoralists have also adopted precision farming techniques.

In addition, new technologies such as genetically modified organisms offer great opportunities for developing sustainable production systems.

There are also opportunities for new sustainable production systems that simultaneously contribute to greenhouse gas-abatement objectives—for example, by increasing carbon stores in soil and through retention of vegetation and the introduction of deeper rooted perennial pasture species. Tree farming in the context of a carbon-trading scheme provides opportunities in regions where current production activity is not ecologically sustainable or where industries are in economic decline. A link between carbon-trading permits and areas where afforestation would provide benefits in alleviating dryland salinity would also assist in sustainable land management.

Scientific innovations such as biomass fuel systems offer efficiencies and benefits in managing natural resources sustainably for productive purposes. Biomass fuel systems lower

the cost of fuels and maintain high levels of organic matter in soils, improving soil structure and productivity. Research into reducing methane from livestock—a big source of greenhouse gases—is well advanced in Australia and may offer commercial and export opportunities in the future.

Although innovation and new technologies can support sustainable production systems it is important that science also fully considers the secondary and tertiary effects of these technologies. It is incumbent on the scientific community to ensure that Australia captures the benefits of new technologies while minimising any negative consequences for the natural resource base. The full examination of secondary and tertiary effects of genetically modified plants on soil microflora and fauna, for example, as part of the approval process for application in the Australian environment will ensure that negative impacts are minimised. Similarly, an assessment of the broader consequences of the use of newly developed high-performance eucalypt hybrids in plantations will minimise unintended consequences.

In some situations, totally new production systems may be required if we are to reach the goal of sustainability. These systems will capture water and nutrients that would otherwise pass the root zone and cause degradation problems. The design of these new systems will rely on science, engineering and innovation. It will entail research into the following:

- rotating and mixing configurations of plants—involving annual and perennial crops, deep-rooted pastures and forage crops and forest and horticultural trees—in space and time;
- configuring plantings in alleys, blocks, windbreaks, and other clusters in the landscape and in rotation of months to many years;
- manipulating phenology, canopy development, the temperature responses of roots, rooting distribution, and the general growth characteristics of both native and commercial plants;
- modifying current crops and pastures through plant breeding, including molecular genetics;
- commercialisation of wildlife species and endemic biological resources.

Science can identify more sustainable production systems, but there will probably still be areas of our agricultural heartland where attempts to restore both environmental and economic health meet with little success. We may have to learn to live with some forms of degradation. Some areas will be irretrievably degraded and lost to traditional production activity; in these areas a change in land use or production mix will be necessary. This will have social ramifications. Science and technology operating within a ‘whole-of-system’ framework will be essential to developing and delivering good solutions—for production and for areas in which production changes or ceases. Science can assist in exploring options for new productive uses in these areas to respond to social and economic imperatives.

**Key observation**

**In some cases, attempts to restore environmental and economic health will meet with little success. We need to be innovative in developing more sustainable systems, which may involve significant social and economic change.**

## 5.5 Providing technological and innovative management solutions

Science is being applied to find management practices that minimise impacts on the resource base and maintain ecosystem health for the future. Science can also deliver new technologies and tools that help managers make sound decisions, increase efficiency in the use of natural resources, and remedy the effects of degradation.

Providing the engineering and technological wherewithal to support decision makers and managers has been a significant contribution by the scientific community. These technologies range from highly complex to relatively simple tools: remote sensing, airborne electromagnetics and satellite imagery help map natural resource conditions and changes over time; ‘real-time’ decision-support systems guide weather-dependent management actions; farm equipment can be adapted to facilitate the use of new farming practices; and hand-held soil and water analysers facilitate the wider adoption of new production systems such as precision farming. Each of these technological advances provides opportunities for better management.

Equally important to treating the impacts of degradation is increasing efficiency in the use of natural resources and finding ways of using underutilised natural resources. This includes a consideration of innovative ways of using natural resources as inputs in the manufacturing process, such as adopting eco-efficiency (see Section 5.7) and new approaches to treating the by-products of degradation. A number of innovative technologies have been developed in Australia in recent years; for example, membrane filters for the treatment of water and waste. More recent discoveries have related to the use of ecosystem services that may have previously been unrecognised, or perhaps unknown; for example, the use of microbiological processes (bacteria and fungi) to break down polluting agents. The use of biological agents to assist in weed and pest control is well established in Australia and continues to offer management opportunities for minimising adverse impacts on the natural resource base.

Innovation, research and technology, and industry development in natural resource management can contribute substantially to solving our unique problems. Moreover, with the international focus on environmentally sound production systems, there are opportunities for Australia to commercialise and export its expertise in natural resource management.

<b>Key observation</b>	<b>Science, engineering and technology will assist in supporting best management practices and provide commercial opportunities for Australia to exploit its expertise in natural resource management.</b>
------------------------	--

## 5.6 Devising decision-support systems

The application of new scientific techniques to support decision making has been an important development for natural resource management.

Sustainable management and production systems are dependent on knowledge and information. The new techniques of predictive modelling enable managers and communities to assess the trade-offs involved in management options. These assessments can be at different scales in the landscape. For example, decision-support systems can help landholders identify the impacts of various management practices or production options on, say, watertable rise, while factoring in the financial returns of those options. They also allow

communities to do integrated catchment-scale modelling to assess the strength of various options and the optimal level of investment to achieve desired outcomes. And they would help governments assess the downstream impacts of changed land use within catchments or regions.

In assessing options, at a range of locations and at the appropriate scale, we need to take into account differences in factors, such as soils, climate and social indicators. In recent years computer-based models have been used to simulate natural systems, integrating the results of many experiments and data from many sources to produce mathematical equations. The equations or models can be used to predict the behaviour or the performance of the system being examined at different locations or under different conditions; for example, the growth of plantations at various sites or under changed climatic conditions (see Box 4).

**Box 4 Simulation modelling: finding the best locations for new plantations**

Developing more plantations serves a number of policy objectives. It provides additional sources for Australia's timber industry, it helps to honour Australia's international obligation to reduce greenhouse gas emissions under the Kyoto Protocol by storing carbon, it provides an alternative commercial option for landholders, and it helps in tackling dryland salinity and waterlogging. But how do we identify available land, the most productive sites for forest growth, the likely returns available as carbon credits, and the right species and sites to treat particular dryland salinity and waterlogging problems?

Predicting and monitoring forest growth across the Australian continent present huge challenges because of the variability of factors such as soils and climate, the availability of suitable land, and the presence of the infrastructure (such as mills) needed to support plantation activities.

Traditionally, forest growth has been estimated using yield models developed at specific locations. These are, however, available only for commercially important species grown in higher rainfall areas. We now need to look at establishing plantations in areas not previously used for commercial forestry, particularly in the 500–800 millimetre rainfall belt on land previously used for agriculture.

The Bureau of Rural Sciences and CSIRO have developed a model that predicts tree growth across the landscape, taking into account local differences in radiation, temperature, rainfall, soil texture, fertility, and water-holding capacity, all of which can vary dramatically within a few kilometres and have a major impact on rates of biomass production. The model can predict forest growth at landscape to national scales, with a level of accuracy for individual sites similar to that obtained using traditional methods. It can also use socio-economic information—such as information on the availability of land and the presence of infrastructure—in conjunction with biophysical data for suitability assessments.

The decision-support services being developed are powerful tools, and their widespread employment is to be encouraged. To be effective, however, they must be founded on sound economic, environmental and social data.

<b>Key observation</b>	<b>Decision-support systems are powerful tools for making informed decisions about the trade-offs involved in management options; the development and wide application of such systems warrant support.</b>
------------------------	---

## 5.7 Providing the factual basis for government and industry policies

Science provides much of the information and methods for designing good policy instruments and assessing different options.

Landholders and other natural resource managers can be encouraged to adopt best management practices through an appropriate mix of government and industry policies. There is a range of policy instruments available, including market-based incentives and voluntary and regulatory approaches.

The following examples—which concern market-based approaches—illustrate how science can play an important part in delivering the right market signals for producers and the community to adopt sound natural resource management practices.

### *Pricing natural resources*

As a general rule, access prices for many of our natural resources do not reflect the resources' intrinsic economic, social and environmental values. Science can help us understand the value of natural resources and the ecosystems of which they are a part and their importance to the sustainability of human activities. Scientific data on the range and extent of off-site and long-term impacts, for example, provide information on external economic costs that are not usually reflected in market values. In many cases under-valuation of natural resources has led to poor management, degradation and over use.

Natural resource managers' actions are determined by the signals they receive from governments, the market and communities. Policies that recognise and incorporate the real value of natural resources will ensure that the right signals are sent to managers.

The Council of Australian Governments (CoAG) water reform program—which includes pricing water services on the basis of consumption, recovering the full cost of providing water, and trading in water entitlements—is an example of placing an economic value on a resource that is subject to degradation. It will have far-reaching effects on the supply and use of water resources for urban, agricultural and industrial use.

The inclusion of environmental values in the national accounts, and moves toward the adoption of environmental audit reports that include a value for maintaining biodiversity as an accounting standard for Australian business, would represent a big step forward.

### *Production standards and accreditation*

The adoption of production standards and accreditation systems will facilitate sound natural resource management practices.

There are two interrelated impetuses for production standards that meet natural resource management objectives: consumer demand and international market standards. A third force is the threat of government regulation if industry does not develop best practice management standards.

We are aware of the growing influence consumers are having on food quality and the move to quality assurance accreditation. In particular, concerns about product quality and

contamination risk (from pesticides, for example) will increasingly affect export markets and prices. If standards are not met, market access will be denied.

In addition, increased attention is now being given—in international forums and by consumers—to the environmental impact of the production process itself. There is a growing trade and market imperative to ensure that best practice production systems are used so as to retain market acceptance for our products. Industry has the opportunity to take the initiative in differentiating Australian products as premium products through the adoption of ISO 14000 and ‘environmental management’ systems (see Box 5). Government support for the development of regimes for accrediting Australian production in the food and fibre industries can facilitate the adoption of standards. Scientists are developing the means to develop and apply such standards at low cost.

**Box 5 International standards for product and environmental quality**

ISO 9000 and ISO 14000 provide some guidelines for the maintenance of product and environmental quality.

ISO 9000 is primarily concerned with ‘quality management’. Its standardised definition of ‘quality’ refers to all those features of a product (or service) that are required by the customer. ‘Quality management’ is what an organisation does to ensure that its products conform to the customer’s requirements.

ISO 14000 is primarily concerned with ‘environmental management’, which means what the organisation does to minimise the harmful effects its activities have on the environment. The standard requires a management system aimed at:

- setting environmental policy and defining environmental goals;
- establishing a program to meet those goals and implementing that program in day-to-day operations and emergency situations;
- measuring performance in achieving those goals and taking action when the targets are not met;
- progressively improving the system by repeating the cycle.

A small number of industries are developing quality assurance and production standards that are transitional, with the intention of moving to ISO 14000 accreditation status. The widespread adoption of production standards and accreditation by industry will provide economic and environmental benefits.

Accreditation regimes rely on good scientific knowledge in the design of environmentally friendly production systems and in the subsequent monitoring of impacts. The science community has four important tasks in this regard:

- to help industry develop appropriate accreditation standards based on sound science;
- to be innovative in developing new, high-standard products for niche markets;
- to develop improved environmentally sound ways of producing food and fibre products;
- to provide data and information to industry in an accessible and relevant form.

### *Eco-efficiency*

More efficient use of natural resources in production systems can lower the costs of production. Box 6 illustrates this.

#### **Box 6 The benefits of eco-efficiency**

'Eco-efficiency' involves producers adopting a systems approach to the production process. Bonlac Foods Ltd—a company producing processed dairy foods—has adopted the eco-efficiency approach. Among other things, it has introduced the use of membrane technology to capture the water from milk condensate, rather than losing it through evaporation. The result is that 90 per cent of Bonlac's water needs (including irrigation at its site at Darnum Park in Victoria) are now met from this single eco-efficiency measure. In three years the company has achieved a number of significant environmental gains, which have contributed to a \$10 million profit.

In addition to lower costs of production, more efficient use of natural resources in production can give Bonlac a competitive advantage: consumers who demand healthy, environmentally friendly goods will seek out its products.

The World Business Council for Sustainable Development has established an eco-efficiency program designed to educate industries about using environmental resources more efficiently. A central goal is to double income for half the amount of resource used—'Factor4'.

It is important to note, however, that thus far all the impressive 'win-win' examples from the Council's programs are site-based manufacturing examples. Achieving the same results from broad-scale resource use (agriculture, forestry and pastoralism) will be more difficult. Science has a role in helping to find and adapt eco-efficiency measures for these sectors as well as for the manufacturing sector.

<b>Key observation</b>	<b>We need a more comprehensive and reinforcing mix of policy instruments that are based on good scientific information and advice.</b>
------------------------	---

### **5.8 Facilitating information exchange**

It is important that sound scientific information and technologies are available so that natural resource managers can make better decisions and adopt sustainable management practices. Science can contribute to this in a number of ways. This paper notes the role of science in facilitating understanding of natural resources' condition at various scales, in helping decision makers obtain data and information in a readily accessible and useable form, and in devising sustainable production systems and management approaches. The exchange of information through partnerships between the research community and natural resource managers is also important: it will result in more relevant research and so encourage the uptake of new techniques and technologies.

Traditionally, the focus of research and development has been determined by the science community and 'top-down' extension arrangements have been used to promote the uptake of new techniques and technologies.

Producers' and natural resource managers' adoption of new techniques and technologies has been disappointing in some areas: better extension strategies and services need to be devised. Economic, educational, institutional and social factors that might inhibit or accelerate rates of adoption need to be considered when designing these extension services.

A change in philosophical approach is gaining momentum, moving from the linear model of technology transfer to an appreciation of what is called the 'agricultural knowledge and information system'. The notion emphasises the knowledge possessed by and flowing between all who are involved: landholders, departments of agriculture, consultants, agribusiness, rural communities, and so on. In this way landholders have more control over the information they need or want and the way it is delivered. Extension is thus directed by a learning and better informed community rather than by science interests.

This approach is being applied by governments and industry-based organisations such as product manufacturers and research and development corporations. In the case of the corporations—where landholders contribute through industry-levied funding to agricultural research, development and extension—industry has directed the focus of research and the uptake of productivity-related research has been high. For natural resource management, the recent and rapid improvement in rural community learning is a positive outcome of the landcare movement.

To increase the relevance of research and development related to natural resource management, and thus the adoption of new management practices and technologies, we need to develop and apply innovative ways of facilitating information exchange between researchers and natural resource managers. This may include greater application of the 'agricultural knowledge and information system', as well as new methods of making data more accessible, relevant and comprehensible for natural resource managers and regional communities. Better information exchange will result in greater relevance and adoption of research products because it will be based on demand rather than science interests.

Natural resource managers and the researchers have much to learn from each other, as has been demonstrated through successful research partnerships (see Box 7). As noted, an interdisciplinary approach to research and development will encourage and facilitate collaborative efforts, ensuring that research is relevant and the results are useful to natural resource managers.

**Key observations**

**Better extension will lead to more rapid and widespread adoption of new technologies and management techniques.**

**Stronger partnerships between natural resource managers and researchers will lead to the development of better solutions that will be more readily adopted.**

**Box 7 Trash blankets and minimum tillage to control erosion in sugar cane**

Since the 1940s soil erosion has been recognised as affecting the long-term sustainability of sugar cane production on sloping land in northern Queensland. Traditional erosion-control methods, using contour banks and grassed waterways, were not adopted because of the difficulty of creating a workable farm layout on steep and broken topography. Rates of erosion ranging from 42 to 227 tonnes a hectare a year on slopes less than 8 per cent were common; on steeper land the erosion rates exceeded 380 tonnes a hectare a year and were as high as 500 tonnes in the Innisfail district. This compares with 2 to 4 tonnes a hectare a year under rainforest and 13 tonnes under pasture.

Conventional cultivation practice involved raking and burning of harvest residues, two passes of primary tillage, another pass for underground placement of fertiliser, and four more passes with a spring-tined implement to control weeds.

A research project conducted over five years with landholders demonstrated that using minimum tillage and retaining the trash as blankets could reduce soil loss from an annual average of 400 tonnes a hectare to 10 tonnes a hectare. It also reduced fuel and operation costs. Yield and cane quality remained similar, so gross margins improved somewhat. The field experiments, conducted at the hillslope scale, gave a dramatic, visual demonstration of the benefits of minimum tillage and the use of trash blankets for erosion control and improved water quality in local streams.

A key to the project's success was landholder and industry involvement from the beginning. To keep trash blankets at about 8 to 10 tonnes a hectare and to have no cultivation once plant cane was established necessitated two important developments by landholders and the industry. They needed a cane harvester that could handle green cane and manage the extra trash, and they needed machinery to deliver fertiliser under the trash blanket. The landholders and the engineering experts in the sugar industry solved both of these problems: the erosion problem was critically undermining the sustainability of the industry.

The research sites were integrated with the demonstration sites and managed by experienced landholders. For five years following the detailed experimentation the sites were used for industry field days and demonstrations. The minimum tillage – trash blanket method was adopted by 80 per cent of cane growers in the region between 1989 and 1994.

## 6 CONCLUDING MESSAGES

We now have a better appreciation of the factors affecting natural resource management. We have expanded our knowledge and invested in new management approaches, and a stewardship ethic has developed in the wider Australian community. Our growing understanding of ecosystem services, landscape function and human activity makes it clear that our natural resource management problems are more complex than we thought. We have moved forward in our thinking and now recognise that degradation is dynamic, continuing and interrelated across the landscape, and it has economic, social and environmental dimensions. But we need to do more.

A change in how we manage and use our natural resources is required. This involves developing farming systems that are in greater harmony with ecosystem processes. This may require making some tough decisions about priorities for use of natural resources. The science community has a vital role to play in helping us to manage and use our natural resources sustainably.

In seeking optimal outcomes, a mix of approaches will be useful, among them larger scale approaches, market-based incentives, regulation and collaboration.

Adaptive management approaches that take into account the dynamic nature of natural processes and the impact of human activity are also important. We will make better decisions when they are based on sound scientific evidence and advice. Decision-support tools, such as predictive modelling, will also help.

In addition to providing information, science has an important role in developing new technologies and innovative management practices to help us deal with our degradation problems and yet remain a productive nation. The Australian science community has an excellent record in innovation; for example, in the development of new technologies, new farming methods, and new plant varieties. This needs to continue. It can contribute to the development of sustainable production systems that use natural resources more efficiently, harness under-exploited ecosystem services, and minimise off-site impacts.

Science itself should be forward looking and based on integrated and ‘whole-of-system’ approaches to investigating current and potential degradation problems and devising solutions. This entails developing stronger partnerships with other disciplines, industry, and natural resource managers.

Government and the science community need to continue to support sustainable and innovative natural resource management that does not degrade our natural resource base or limit the future for our economy, society or environment.

## 7 THE KEY OBSERVATIONS LISTED

- We have made progress in managing our natural resources, but we need to do more.
- Natural resource management issues are dynamic and complex; it requires a sustained scientific commitment.
- Natural resource degradation and change constitute a continuing and serious problem for Australia.
- The factors that cause degradation are interrelated, and degradation problems should not be viewed in isolation; they should be viewed from a 'whole-of-landscape' perspective.
- The extent and rate of continuing degradation require that we continue to search for new approaches to ensure that our natural resources are managed and used in a way.
- The scientific research effort needs to be interdisciplinary, and use collaborative mechanisms to take account of the social, economic and environmental aspects of natural resource management.
- Data on the condition of and trends in our natural resources—at farm, local, catchment, regional and national scales—need to be assembled on a continuing basis and to be readily accessible in a useable form. Cost-effectiveness should be an important criterion for data collection.
- Local and regional community groups and landholders should be trained in data collection and analysis techniques to assist in developing regional strategies and whole-farm plans.
- Adaptive management approaches—a practical response to the lack of knowledge about appropriate natural resource management practices—should be encouraged.
- The development of management approaches at the appropriate scale—including regional-scale projects—should be based on sound scientific knowledge and advice.
- Australian production systems need to be more in tune with natural processes and to operate within the capacity of the natural resource base.
- In some cases, attempts to restore environmental and economic health will meet with little success. We need to be innovative in developing more sustainable systems, which may involve significant social and economic change.
- Science, engineering and technology will assist in supporting best management practices and provide commercial opportunities for Australia to exploit its expertise in natural resource management.
- Decision-support systems are powerful tools for making informed decisions about the trade-offs involved in management options; the development and wide application of such systems warrant support.
- We need a more comprehensive and reinforcing mix of policy instruments that are based on good scientific information and advice.
- Better extension will lead to more rapid and widespread adoption of new technologies and management techniques.
- Stronger partnerships between natural resource managers and researchers will lead to the development of better solutions that will be more readily adopted.

## 8. RECOMMENDATIONS

It is recommended that the Prime Minister’s Science, Engineering and Innovation Council (PMSEIC) endorse the key observations and recommendations in this paper and agree that the Commonwealth Government encourages the scientific community to take the following actions, as appropriate:

1. adopt a more anticipatory and integrated approach to research and development that takes into account production, resource sustainability, and socio-economic factors;
2. note the valuable contribution of the National Land and Water Resources Audit and support a continued commitment to the collection and analysis of baseline data and indicators to increase our capacity to monitor and evaluate performance and progress;
3. adopt a mix of policy instruments—among them market-based incentives and industry production standards—that are based on good scientific information and advice;
4. remedy problems at the most appropriate scale, including at larger scales such as the regional level;
5. establish a collaborative, coordinated process designed to identify national priorities for research that will inform policy and the practical management of our natural resources;
6. develop, in partnership, more integrated policies and strategies for targeting research and large scale regional responses to natural resource management issues;
7. facilitate the development of stronger partnerships between researchers and natural resource managers that will lead to more relevant and practical research and improved information exchange.

It is also recommended that PMSEIC agree:

8. that relevant Ministers write to the scientific research organisations in their respective portfolios advising of their agreement to the above recommendations;
9. to seek advice on whether there are impediments, particularly institutional, to interdisciplinary research—integrating economic, social and environmental dimensions—and, if so, the ways to overcome these impediments.

## 9. ACKNOWLEDGEMENT

This paper was prepared by the Natural Resource Management Scientific Advisory Group. Members include:

Mr Bill Handke (Chair)  
Department of Agriculture, Fisheries & Forestry

Dr Colin Chartres  
Bureau of Rural Sciences

Professor Peter Cullen  
Cooperative Research Centre for Freshwater Ecology  
University of Canberra

Associate Professor Rodger Grayson  
Dept of Civil and Environmental Engineering  
University of Melbourne

Dr Ann Hamblin  
Bureau of Rural Sciences

Dr Graham Harris  
Land & Water Division  
Commonwealth Scientific and Industrial Research Organisation

Dr Brian Walker  
Wildlife & Ecology Division  
Commonwealth Scientific and Industrial Research Organisation

Dr John Williams  
Land & Water Division  
Commonwealth Scientific and Industrial Research Organisation

Ms Carol Cribb (Executive Officer)  
Department of Agriculture, Fisheries & Forestry

---

The Group may be contacted through its Chair:

Mr WA Handke  
Assistant Secretary  
National NRM Policy Statement Task Force  
Natural Resource Management Policy Division  
Competitiveness and Sustainability Group  
Agriculture, Fisheries and Forestry - Australia  
GPO Box 858  
Canberra ACT 2601  
Phone: 02 6272 3393  
Fax: 02 6272 4960  
email: [bill.handke@affa.gov.au](mailto:bill.handke@affa.gov.au)

---

*The paper was prepared by the Natural Resource Management Scientific Advisory Group for the Minister for Agriculture, Fisheries and Forestry.*