FARMING IN AN ANCIENT LAND – AUSTRALIA'S JOURNEY TOWARDS SUSTAINABLE AGRICULTURE.

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Abstract
Agriculture is a very recent experience for the ancient Australian landscape. Two hundred years of "European" agriculture is but a instant in comparison with 60000 years of a continuous indigenous human civilisation, 30 million (Ma) years of unique biological evolution in an isolated island continent and over 600 million (Ma) years of geological history during the break-up of the Gondwanaland super-continent. Yet this brief period of agriculture has had dramatic consequences for Australian ecosystems and the land and water resources that agriculture continues to rely on. The National Land and Water Resources Audit in 2000 paints a stark picture of degraded soils through salinity, acidification and erosion, degraded catchments through nutrient and sediment loss to waterways, over-exploited water resources, and loss of biodiversity in native plant and animal communities.

Sustainable land management was something indigenous Australians effectively achieved, but it remains an aspiration for present day agriculture. One interpretation of this is that it has taken all of the 200 years of agriculture's history in Australia for us to understand how poorly adapted European style agriculture is to this flat, salty ancient landscape with its fragile and relatively infertile soils. Another clearly lies in our far more relentless pursuit of economic development at the expense of the continent's natural capital.

While agriculture was the foundation of the present day Australian society and economy, its significance in terms of GDP, exports and employment is now much reduced - yet it continues to command an important place in the national psyche and political landscape. Agriculture is likely to remain profitable in locations and circumstances where resources, markets, management and innovation allow, although increasingly we expect to see Australian society valuing the non-production aspects of agriculture (ie. agro-ecosystem services such as clean water supplies, greenhouse gas abatement, catchment management, flora and fauna conservation, open space and amenity values). Regardless of the future economic and social drivers for agriculture, the skilful combination of scientific and practical knowledge will remain the essential vehicle on this journey towards sustainability.

Additional Keywords: NLWRA, audit

Introduction

To appreciate the present day relationships between agriculture and the Australian environment, we need to go back in time and understand the geological, biological and climate forces that have shaped this continent. If we were to compress 600 million years of Australian natural history into a single day, we would see the arrival of indigenous Australians around 8 seconds to midnight and the arrival of Europeans and their agriculture at around 3 milliseconds to midnight. Agriculture is clearly a very recent phenomenon in a very ancient Australian landscape. Moreover, this agriculture was first conceived through European eyes, more attuned to the soft and nurturing landscapes of England and Ireland than the harsh and fragile lands to be found on the other side of the world.

In this paper we aim to take you on this journey - starting with the break-up of the super-continent Gondwanaland over the period 30-600 million years (Ma) ago, moving through the 30 Ma period of isolation as the unique Australian flora and fauna evolved, to the 60000 year history of indigenous human occupation and finally the 200 years or so of European settlement and agricultural development. This most recent period, while only an instant in the context of the forces that have shaped the Australian continent, has been the most dramatic in terms of the rates of transformation of the natural landscape. The paper draws heavily on the recent National Audit of the state of Australia's land and water resources - this audit reveals the extent to which the land and water resources used for agriculture and the associated natural environment, have been degraded in the process of developing the present day Australian economy.

The Australian landscape has been on a long journey – sustainable for most of its history but clearly unsustainable in more recent times in the face of agricultural development. In 2004, Australia's agricultural lands are in need of what is stated as the theme of this session in the ISCO Conference, namely – "Scientific and practical knowledge for creating solutions". The paper concludes with a brief exploration of some key scientific and practical pathways forward for Australian agriculture.

Gondwanaland – Over 600 Million Years Adrift in the Northern and Southern Seas

Australia is an ancient land, having over 3.8 billion years of geologic history (Parkinson, 1988; Paine, 1992). Much of the Australian landscape today reflects this antiquity, with relatively low relief, eroded hills and plains, exposed ancient rocks and well leached and infertile soils (Taylor, 1994). This is particularly evident in the western half of the country, where the oldest rocks are exposed (Parkinson, 1988; Taylor, 1994). The consequences of this is that much of our landscape is deficient in nutrients and prone to problems such as erosion, acidification and salinization when used for agricultural production (Walker *et al.*, 2001).

Throughout its long history, the Australian landscape has been shaped by geomorphic processes (including volcanism, uplift and erosion), marine incursion, climate and biological change. Compressional tectonics, however, have played only a minor role in the evolution of Australia (along areas marginal to eastern and north-western Australia and in Tasmania), hence the relatively low relief and absence of high mountains. The few high mountains that have been formed in the past during episodes of uplift (such as the Darling Range) have since been eroded (Quilty, 1994; Johnstone *et al*., 1973; Veevers, 1984). Indeed, erosion and chemical weathering have been important processes in the development of the Australian landscape, dominating in the central areas during periods of warm, wet climates (Quilty, 1994). For example, between 600 and 700 m has been degraded from the Yilgarn-Pilbara Plateau in western and south-western Western Australia over the last 600 million years (Veevers, 1984). Weathering under warm, humid conditions during the Tertiary (65-2 million years (Ma)) was responsible for the widespread deposition of laterites and silcretes (Parkinson, 1988).

Uplift and volcanism have also played important roles during periods of Australia's development, particularly in the east and southeast. One of the most significant products of these processes that is still dominant in the landscape today is the Eastern Highlands. Extending along the east coast of Australia from Tasmania to north Queensland, the highlands consists of uplifted predominantly early to mid-Palaeozoic (ca. 550-350 Ma) marine sediments and Cainozoic (65 Ma to present) basalts. Uplift of the highlands is thought to have commenced at least 100 Ma, and probably earlier (Taylor *et al*., 1985; Williams, 1989), although there is some debate about the timing (Taylor, 1984). Concomitant with this uplift was the deposition of sediments in the adjacent basins, such as the Murray, Gippsland, Otway and Eromanga basins (Figure 1; Macumber, 1978; Wooley, 1978; Veevers, 1984; Brown, 1989).

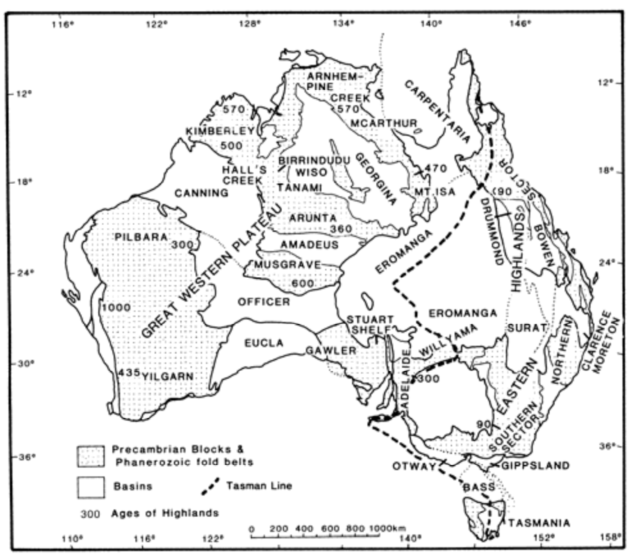

Figure 1. The major tectonic provinces of Australia, including the major lowland depositional basins, the Palaeozoic (600-250 Ma) accretionary terrains (east of the Tasman Line), and the major cratonic blocks that make up much of the Great Western Plateau (source: Tyler, 1994).

Marine transgressions and regressions have also played important roles in the development of these basins. Widespread inundation and the associated deposition of marine sediments occurring during the early to mid-Cretaceous (141-97 Ma) and Tertiary (65-2 Ma) periods. These were interspersed with phases of regression, where there was significant deposition of terrestrial sediments (including quartz rich fluvial and alluvial sediments) as well as episodes of weathering and erosion (Parkinson, 1988; Struckmeyer, 1992; Taylor, 1994). The ancestors of the Murray and Darling rivers formed during the final Late Cretaceous marine regression, which was accompanied by the northward movement of the drainage divide (Quilty, 1994).

Changes in the Australian climate, brought about by a combination of shifts in global temperatures, ocean and atmospheric circulation and continental drift, have affected both sedimentary and biological processes in the evolution of the Australian landscape (Struckmeyer, 1992; Quilty, 1994). Australia, in its various stages of formation, has been drifting around the globe for at least the last 600 million years, much of it as part of the Gondwana supercontinent (Figure 2). During the early Palaeozoic (600-400 Ma) Australia, as part of Gondwana, was located in low latitudes (5-40 °N). Climates were generally warm, with abundant rainfall in the western half of the continent and possibly more arid conditions in the south. This led to the deposition of carbonates (including reefal limestones) and evaporites. The Australian climates became colder through the late Palaeozoic (400-250 Ma) as Australia (still part of Gondwana) moved southward (as far as 70 °S). This culminated in the development of an ice sheet across southern and central Australia, with large ice bodies in the west and central Australia, and the accompanying deposition of glacial sediments as well as erosion of pre-existing strata (Frakes and Rich, 1986; Parkinson, 1988; Struckmeyer, 1992; Taylor, 1994). Gondwana began to break up during the Mesozoic (250-65 Ma), with Australia commencing its break away from Antarctica around 140 Ma (mid-Mesozoic) and completing it by 30 Ma, during the Cainozoic (Quilty, 1994; Wilford and Brown, 1994). Since then, Australia's flora and fauna, much of it relict from the Gondwana supercontinent, has developed in isolation (Parkinson, 1988). With the break up from Antarctica, Australia began to drift northward at an accelerated rate, leading to the collision with the Pacific Plate and the creation of the highlands of New Guinea (Struckmeyer, 1992).

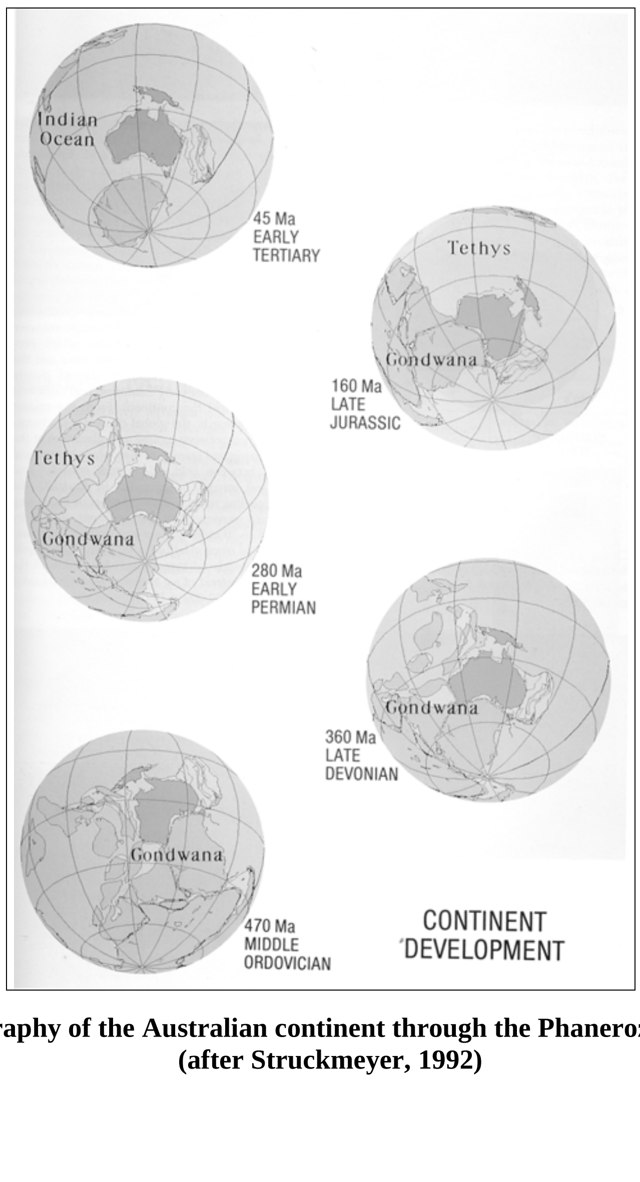

Figure 2. Palaeogeography of the Australian continent through the Phanerozoic (600 Ma to present) (after Struckmeyer, 1992)

Climates during the Mesozoic were generally temperate to very warm, leading to the development of a diverse flora. By the early Cainozoic (65 - 45 Ma) rainforest dominated much of the continent under a warm wet climatic regime. Climates became cooler and drier in Australia from around 38 Ma, however, with the establishment of circum Antarctic oceanic flow, the development of large scale ice sheets on Antarctica and the subsequent steepening of the temperature gradient form pole to equator (Kemp, 1978; Struckmeyer, 1992; Wilford and Brown, 1994). Drier climates promoted the widespread development of duricrusts across the continent as well as the rise of sclerophyllous plants (such as the Myrtaceae and Asteraceae) and drier, more open vegetation (particularly in the central and southern mainland regions) (Struckmeyer, 1992; Kershaw *et al*., 1994). By 15-20 Ma, the northern part of Australia had drifted into the tropical monsoon climatic zone (Struckmeyer, 1992; Wilford and Brown, 1994). By 7 Ma global climates had cooled enough to allow the development of ice in the Northern Hemisphere (Larsen *et al*., 1994), heralding the commencement of global climatic fluctuations in cycles of warm (interglacial) and cold (glacial) periods, the latter being characterised by the development of continental ice sheets and glaciers (Williams *et al*., 1998). Although ice cover during the cold, Quaternary glacial phases has been very limited in Australia (occurring only in the Kosciusko region and in western Tasmania), the shifts in climate have had significant impacts on our vegetation, soils and history of human occupation (see the next section for the latter). Increased aridity in Australia, particularly from 500 Ma (Bowler, 1982; An *et al*., 1986) has resulted in the rapid decline in rainforest taxa and the expansion of more open, drought tolerant communities (such as eucalypt woodland and grassland (Kershaw, 1988; Kershaw *et al*., 1994; Martin, 1989, 1990; McEwan-Mason, 1991). It has also caused the mobilisation of sand sheets and dunes across much of southern and central Australia, particularly during the cold glacial phases (Bowler, 1982; An *et al*., 1986; Hesse, 1994). It wasn't until relatively recently (between 5 and 3 ka), however, that one of the climate phenomena that dominates our landscape today, the El Niño Southern Oscillation, really became active (McGlone *et al*., 1992).

Today, much of the Australian landscape is extraordinarily flat. For instance, as Williams and Goss (2003) remind us, the Murray River, which drains a catchment of 1061469 km^2 of major significance for agriculture (14% of the Australian land surface), falls just 200 m over a river length of 1000 km. The Murray-Darling system is for all intensive purposes, a closed slowly moving groundwater system with a very restricted outlet provided via the Murray mouth.

Australia is not only very flat, but it is also very salty. Salts from rock weathering and deposits in rainfall over the last 30 million years have built up in soils, sediments and groundwaters. The combination of low rainfall and very slow rates of transmission in flat landscapes and slowly moving groundwaters means that these salts have built up to massive quantities. For instance, the soils of the Murray-Darling Basin are estimated to contain over 100 billion tonnes of salt and annual inputs to this basin, in the order of 2.8 million tonnes salt per year (Jolly *et al*., 1997) still exceed estimated annual outputs of 1.75 million tonnes salt/year via the Murray River at Morgan (Newman and Goss, 2000).

Australia's agricultural landscapes today are shaped by another legacy of the continent's ancient past. Soils, with some exceptions where more recent basaltic volcanics have had an influence, are generally shallow, light textured and infertile – often exhibiting multiple deficiencies of nutrients essential for growth of anything other than highly adapted, slow growing native species. Subsoils are often inhospitable to root growth, exhibiting a range of physical and chemical constraints (Rengasamy, 2002).

Over the 30 Ma since the Australia continent separated from Antarctica and began its solo journey northwards, the fauna and flora have evolved in very special ways. So while present day agriculture has been built upon this legacy of relatively infertile, fragile soils in a flat and salty landscape, it has displaced, to varying degrees, a highly diverse native biota, unlike anything else on earth. Over 80% of Australia's mammals, flowering plants, reptiles, frogs, fungi, molluscs and insects known only to occur in Australia (Williams *et al*., 2001).

Dreamtime: 40-60 Thousand Years of Aboriginal Land Stewardship

Aboriginal people are generally thought to have first arrived in Australia between 40 and 60 thousand years ago - hopping from south-east Asia across islands and land masses exposed by sea levels up to 65 m below those of today (Figure 3; Mulvaney and Kamminga, 1999). While this is the academic and prevailing non-indigenous view, supported by archaeology, it is important to note that many indigenous people believe they originated in Australia and have been here since time immemorial.

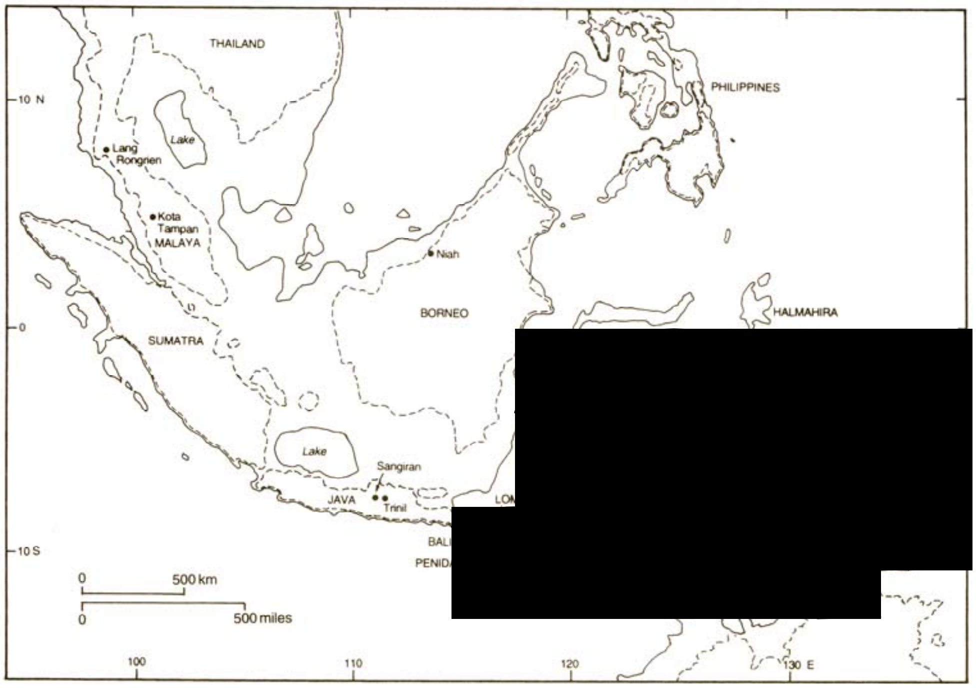

Figure 3. The coastline of Australia and South-east Asia when the sea level was 65 m below that of today. Dotted lines indicate the present coastlines. The arrows signify potential routes of Aboriginal migration (adapted from Mulvaney and Kamminga, 1999).

The landscape that met these early Australian migrants would have been very different to that of today and vastly different to the one they had travelled from, particularly as they moved away from the northern coast. The climate was that of a glacial phase, with reduced rainfall, temperature and evaporation. Large areas of Australia's continental shelf were exposed (due to low sea levels) and covered by a mosaic of lakes, marshes, grassland, open shrubland and sclerophyll woodland. The regional vegetation of Australia consisted mainly of grassland, shrubland and open woodland, with isolated patches of forest and rainforest in sheltered and higher rainfall areas along the eastern seaboard, in the southeast and southwest (Hope, 1994). Between 30 and 50 thousand years ago (ka), the arid zone would have been contracted in comparison to today, with lower evaporation rates allowing the inland lake and river systems to be more active (Bowler, 1982). Permanent snow and ice occurred in the southeastern highlands and western Tasmania. Megafauna still roamed the continent, as did fauna that were later to become confined to Tasmania, such as the Tasmanian Devil and Tasmanian Tiger (Johnson and Wroe, 2003). As the Aboriginal people began to explore this strange new land, they would have had to adapt not only to a range of new environments, but also to a fluctuating and ever deteriorating climate as conditions moved toward the Last Glacial Maximum 23-18 ka. During this phase arid and semi/arid areas expanded significantly, dunes became more active, dust storms swept much of the country, and the vegetation became more open with far fewer trees and further fragmentation of forests (Hope, 1994). The megafauna also disappeared, most probably due to a combination of pressures from climate and humans, although this is hotly debated (for a summary see Mulvaney and Kamminga, 1999). Similarly, as climates became warmer and wetter around 10 ka with the onset of the current interglacial (the Holocene), the Aboriginal people would have had to adapt to a rapidly changing environment, with sea levels rising, ice and snow disappearing from the highlands, vegetation patterns shifting, the nature of the seasons changing and lakes in the central areas drying whilst others nearer the coast filling.

By 25 ka, most habitats of Australia had been colonised (Mulvaney and Kamminga, 1999) and Aboriginal people had began to leave a mark on the Australian landscape, although the extent and nature of this is debated (Head, 1989). Palaeoecological records indicate that the Australian vegetation has undergone significant change over the last 40 ka, partly in association with climate but also in association with charcoal evidence for increased burning (eg. Harle *et al*., 2002; Kershaw, 1993). The latter has been attributed to the strategic use of fire by the Aboriginal people to, among other things, maintain grasslands and open vegetation as a way of promoting target species of fauna and flora (Jones, 1969; Kershaw, 1993). The result has been the transformation of much of the Australian landscape to one of more open, fire adapted and eucalypt dominated vegetation.

The fact that Australian Aborigines have survived and expanded their occupation of Australia through 40-60,000 years of variable climates and landscape conditions is testimony to their ability to adapt and to the resilience of their methods for exploiting the landscape. This is at least in part due to the hunter-gatherer nature of their lifestyles, with its inherent mobility and associated ability to adapt to change. For example, as the lakes dried up in the arid interior, and with them valuable food and water resource, they were abandoned in favour of more amenable environments towards the coast (Mulvaney and Kamminga, 1999). It may also be in part due to their relationship with the land, one that has been forged over tens of thousands of years of environmental change and variability. To the Aboriginal people, Australia actually consists of a complex set of "countries" or regions occupied by different language groups (Mulvaney and Kamminga, 1999). There is no imposition of common concept of landscape conditions onto these regions, such as the four-season climate that European settlers have imposed on much of Australia. Rather, each region is viewed according to the traditions, value systems and knowledge basis of each tribal group. Integral to this is the "…attachment of people to place through the mediating process of the ancestral past…." (Morphy, 1995, p186). For example, the Yolngu people of Arnhem Land, as well as other Aboriginal groups, view rights of land through a charter of interwoven religious, historic and economic values (Williams, 1986). Thus, they have a system of land allocation with estates of land-owning groups made up of non-contiguous lands, usually one major coastal and one inland area, which together provide the resources required for each group to survive (Williams, 1986). It is also important to remember, that Aborigines view the landscape as "…a set of spaces for people to occupy" (Morphy, 1995, p186). In this respect, they share common ground with post-European Australia, although it could be argued that there is a fundamental difference in how the nature of such occupation is viewed.

White Fella Coming – 200 Years of European Agriculture

The first Europeans arriving in Australia (many not of their own choosing!) also found a very alien world - populated by a people with very ancient and very different traditions, a unique flora and strange animals (some such as the platypus thought to be a hoax when specimens were received in England in 1799 (see Moyal 2001)). Even a mind as open to the power of evolution as Charles Darwin was taken to record in his 1836 *Beagle* journal entry:

I had been [. . .] reflecting on the strange character of the animals of this country as compared with the rest of the world. An unbeliever in every thing beyond his own reason might exclaim, 'Two distinct Creators must have been at work…" … Darwin 1989 [1839]

Early attempts at agriculture were problematic - droughts, infertile soils, poorly adapted species and practices to a very different climate, 180 degrees out of alignment with the European experience. The fledgling penal colony nearly failed in those early years and relied on food shipments from England for survival – and this in a place where the indigenous population had lived successfully for 40-60000 years. An ex-convict named James Ruse was the first to demonstrate he could survive independent of the government stores in 1789/90. For his efforts, Ruse was rewarded with the first land grant in Australia amounting to 30 acres at Parramatta, near Sydney. Over the next 150 years, Australia learnt to "ride on the sheep's back" - to become a prosperous nation based on an agrarian economy, exporting wheat, wool, sugar and other commodities. Many would say the indigenous Australians were largely forgotten over this first 150-200 years, as Australia rushed headlong into developing the country through "taming the bush".

While it is true to say that agriculture in Australia started from a European sense of farming and environment, it would be wrong to suggest that the need to adapt agriculture to the Australian environment and landscape was not recognised. In fact, the next 150-200 year history of the development of Australian agriculture is one of practical and scientific innovation to overcome the special challenges encountered here. Innovations in animal breeding (eg. Macarthur's merinos), plant breeding (eg. Farrar's Federation wheats), mechanisation (eg. Sunshine Harvester, stump jump plough), and the science of plant nutrition (eg. discoveries on essential micronutrients) are just a few of the key achievements that allowed agriculture to spread across the Australian landscape. Still, despite this culture of innovation and adaptation, Australian agriculture has largely remained within the European paradigm of annual cropping and hoofed animals - two elements that at odds with the continent's ancient natural history. These dominant agricultural practices are more at home in young, robust landscapes of Europe than the ancient, fragile landscapes found in much of Australia. Over the last 30 years, the impacts of 200 years of European agriculture are becoming more apparent. In particular, the disruption and unbalancing of water and nutrient cycles is increasingly recognised as a root cause of much landscape degradation (Williams, 1999; Williams and Gascoigne, 2003). The state of the resource base for agriculture and the condition of the natural environment influence by agriculture, is explored in the next section of this paper.

Australian Agricultural Landscape in 2004

An audit of Australia's natural resources

Recognition of the degradation in Australia's natural assets over the 210 years since the arrival of Europeans reached a significant milestone in 1997 when the Commonwealth Parliament passed the "Natural Heritage Trust of Australia Act 1997". The preamble to this Act states;

"… the need for urgent action to redress the current decline and to prevent further decline in the quality of Australia's natural environment …. to conserve Australia's environmental infrastructure, to reverse the decline in Australia's natural environment and to improve the management of Australia's natural resources …. To integrate the objectives of environmental protection, sustainable agriculture and natural resource management consistent with the principles of ecologically sustainable development …"

The National Land and Water Resources Audit (NLWRA) was established under this Act to "… improve Commonwealth, State and regional decision making on natural resource management". Over the next 5 years, a broad ranging series of assessments were undertaken with respect to surface and groundwater management, river, estuary and catchment health, dryland salinity, vegetation cover, condition and use, rangelands monitoring, land use, productivity, profitability and sustainability of agricultural enterprises, social and economic capacity for change in natural resource management and terrestrial biodiversity. Importantly, and often for the first time, these assessments were based on consistent national approaches and frameworks for NRM assessment and information management. We draw heavily upon the NLWRA as we attempt to provide an overview of the "state of play" in Australia's agricultural industries and landscapes in 2004.

Australia's agro-ecological zones and characteristics

With a surface area of 7.6 million km^2, extending from latitude 10^{o}S to 45^{o}S, Australia exhibits a diverse range of agro-ecological zones (Figure 4). After Antarctica, Australia is the next driest of the Earth's continents, with an annual rainfall averaged over the continental land surface of 465 mm (compared to a global land surface average of 777 mm). Such averages fail to convey the spatial diversity (from < 200 mm in central Australia to > 3000 mm along the wet tropical Queensland coast (Figure 5). Only 25% of the continent has a growing season greater than 5 months and this fraction drops to 9% for regions with a nine month growing season.

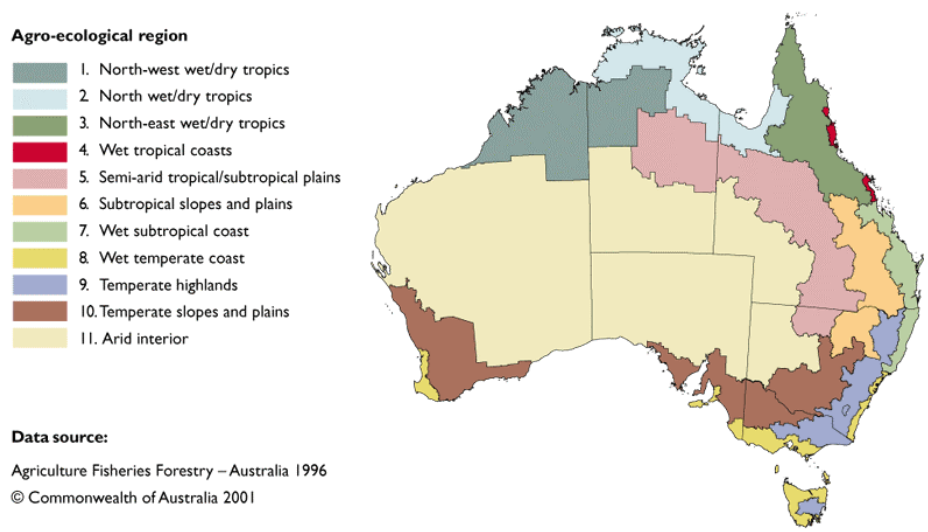

Figure 4. Australia's agroecological zones. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp3)

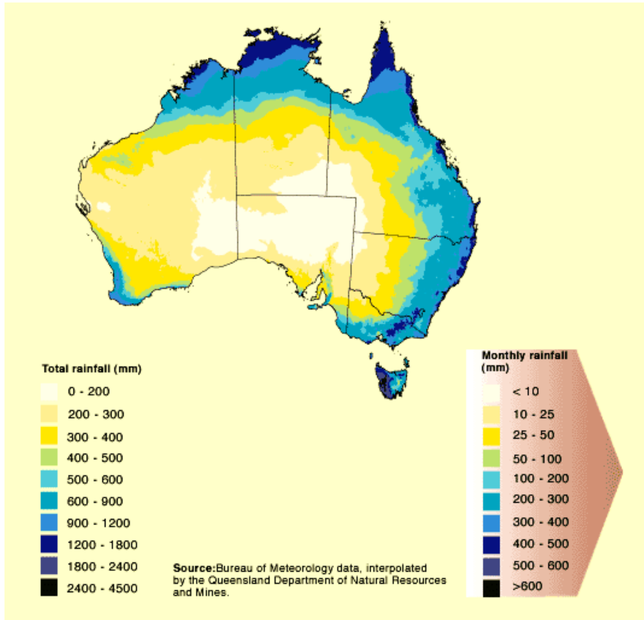

Figure 5. Mean annual rainfall for Australia. (from NLWRA (2001) Australian Agriculture Assessment 2001, pp 42)

A comparison of the Australia's continental water balance with other regions of the world reveals just how dry a place this is. Evaporation (from soils and plants) dominates Australia's water balance and the continental annual average runoff term of 52 mm is only one sixth of the global land mass average.

Rainfall, soils and topography combine such that a mere 6% of the continent is considered arable. These "intensive land use" zones, located along the eastern, south-eastern and south-western seaboards are the focus of this paper. These agricultural lands can be found within the sub-tropical and temperate slopes and planes (AEZ 6 and 10 in Figure 4) and the wet tropical, sub-tropical and temperate coasts (AEZ 4, 7 and 8 in Figure 4). Another contribution to this conference will focus on the large areas of extensive rangelands that occupy the interior and north of the continent (Figure 4).

Australia's agricultural systems

Nature and extent

"Intensive" agriculture (based on cultivation of annual or perennial crops and pastures for plant and animal products) accounts for only 6% (27.4 million ha) of the total 454 million hectares of rural production in Australia. The balance is used for extensive pastoralism. The national land use map in 2001 (Figure 6) shows a continent dominated by extensive livestock grazing and nature conservation / resource protection in the Central Australian and Western Australian deserts. The agricultural zones dominated by dryland mixed crop-livestock farming are to be found in south-west Western Australia, and an arc starting in South Australia, running through Victoria, New South Wales and into southern/ central Queensland. This mixed farming zone can be found in the 300 to 500 mm annual average rainfall zone in southern Australia and the 400 – 600 mm zone in more northern regions. A narrow coastal strip supports horticulture and intensive cropping industries such as sugarcane and intensive livestock industries such as dairy.

Irrigation has expanded significantly in area over the last 50 years, and now over 2 million ha (approx. 7 percent of "intensive" agriculture) is irrigated for dairy pastures, cereal crops, cotton, sugarcane and horticulture, mostly located in the Murray-Darling Basin (MDB) and the Queensland coastal river systems (Figure 7).

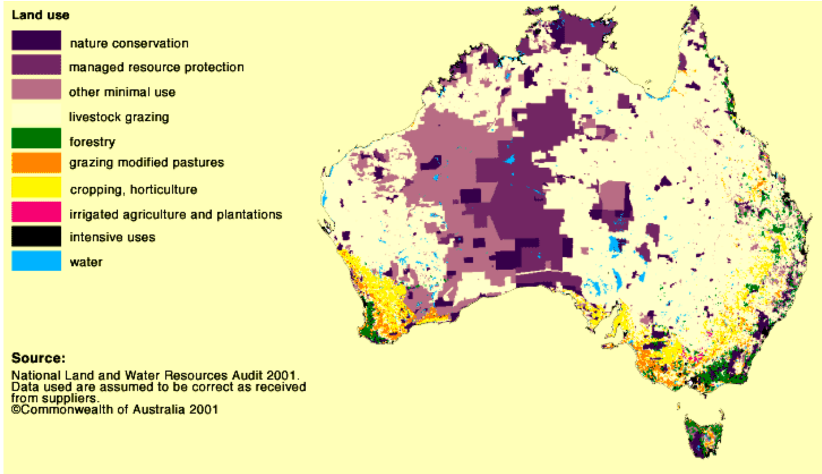

Figure 6. Australian land use. (from NLWRA (2001) Australian Agriculture Assessment 2001, pp 6)

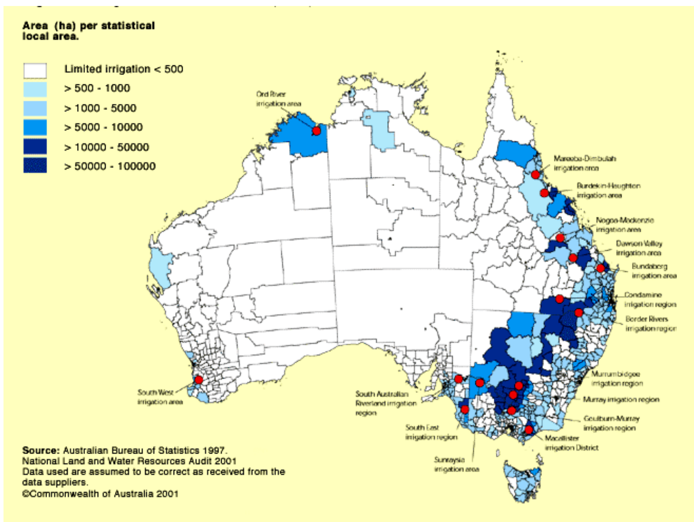

Figure 7. Irrigated areas of Australia in 1997 (from NLWRA (2001) Australian Agriculture Assessment 2001, pp 7)

<u>Profitability of Australian agriculture</u>

Farmers terms of trade (the ration of prices received to production costs) have declined dramatically over the last 40 years (Figure 8). The net value (on a real basis) of agricultural production whilst highly variable, has also followed a declining trend (Figure 8). Many of Australia's agricultural systems exhibit low levels of profitability (when calculated at full equity - including an allowance for the costs of farmer's labour and depreciation of capital) (Figure 9). Profit at full equity represents the return on all the resources used in the farming business. Over the five year period, 1992/93 to 1996/97, the profitability (at full equity) of Australian agriculture averaged $7.5 billion. The top four contributions came from dairy (22%), cereals (17%), cotton (14%) and fruit (13%) (Table 1).

Eighty percent of all profits generated over the 1992-1997 period were estimated to come from only 4 million ha (i.e., <1% of all land used for agriculture and pastoralism or approx 15% of all the more intensive lands used for cropping, intensive livestock or horticulture (Figure 10). Half of all these profits in 1996-97 came from irrigated agriculture which accounted for approximately 7% of intensive land use and was most prominent in the MDB and to a lessor extent, central Queensland.

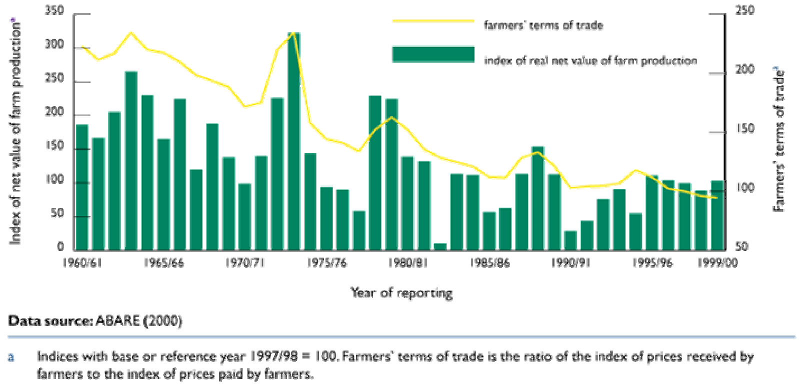

Figure 8. Farmers terms of trade and real net value of agricultural production. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.71)

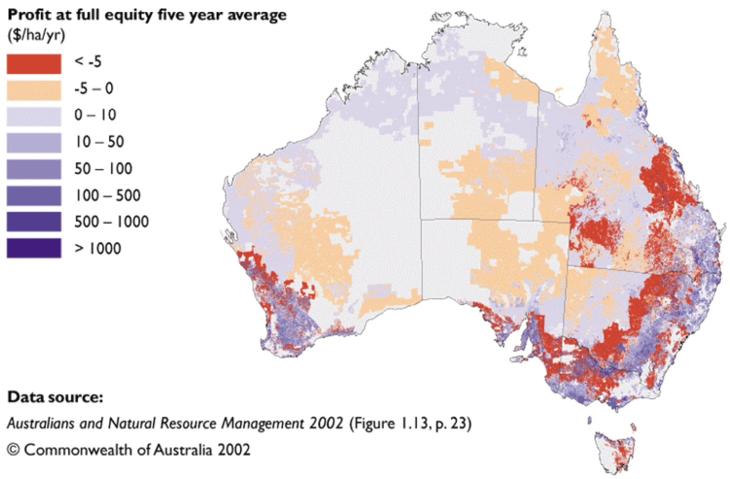

Figure 9. Profit at full equity for Australian agriculture (average 1992-1996). (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.68)

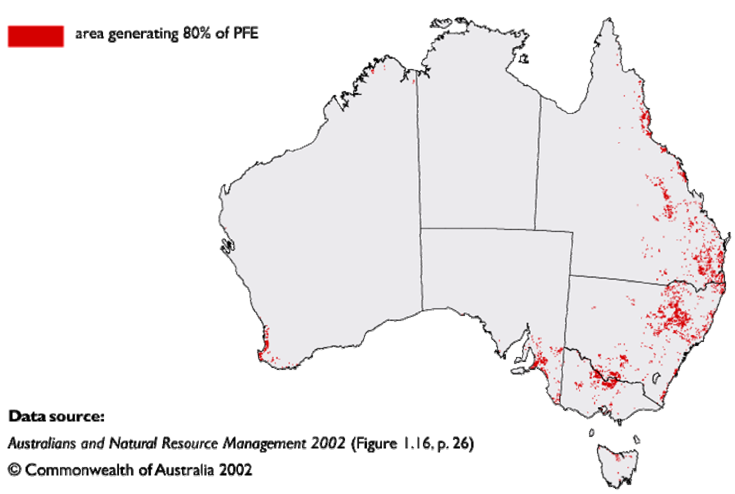

Figure 10. Areas in Australia accounting for 80% of profit at full equity in 1996/97. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.68)

Table 1. Profit at full equity by dominant land use type. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.66).

Land use*	Five-year mean ($m)	1996/97 ($m)
Dairy	1 649	1 590
Cereals	1 305	1 836
Cotton	1 089	1 213
Fruit	951	889
Coarse grains	649	560
Vegetables	593	508
Beef	578	-718
Grapes	482	468
Sugar cane	264	167
Tree nuts	68	71
Oilseeds	63	93
Rice	48	52
Legumes	19	85
Peanuts	17	23
Tobacco	15	13
Hay	9	11
Sheep	-270	-306
Total	**7 530**	**6 555**

*Figures are Australia wide including extensive and intensive agriculture. They have not been segmented industry sectors, such as intensive beef or feedlots. Profit from production from mixed farming enterprises (eg. a wheat -sheep farm) are proportionately reported within each 'land use' class.

Agriculture in the Australian economy

The significance of agriculture in the Australian economy in terms of contribution to employment and GDP has been declining for an extended period. Over the last 50 years, agriculture has declined from 80% of GDP to under 5% of GDP and employment from over 40% to under 10% (Figure 11). The dominance of agricultural products in Australian exports has also declined. Including pastoralism, the annual gross value of production at farm gate averaged $25 billion and exports $17.6 billion over the 1989–99 period. Agriculture represented only 3% of Australia's gross domestic product (GDP) of $620 billion over that same period, but more significantly 20% of all export income (NLWRA, 2002a, pp. 4).

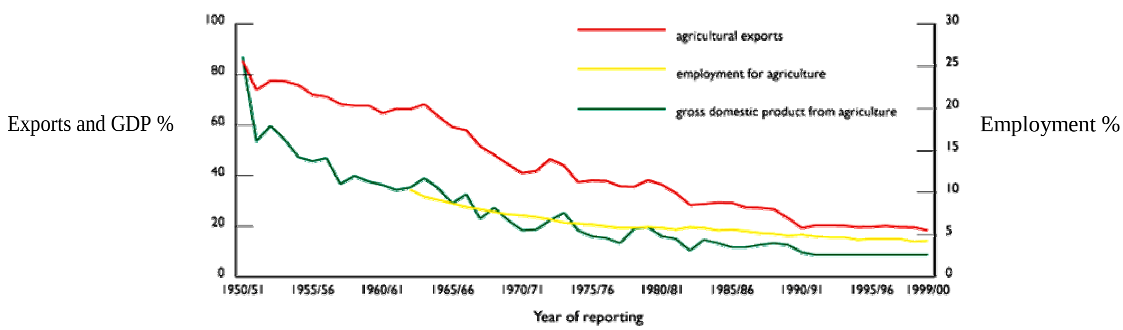

Figure 11. Contribution of agriculture to economic growth, employment and exports for Australia, 1950/51 to 1999/00. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.71)

The social context of Australian agriculture

Australian farms are getting fewer and larger on average (Figure 12) and Australian farmers are getting fewer and older (Figure 13). Farm family incomes are broadly similar to the rest of the community (Figure 14) but off-farm incomes are generally increasing in significance in the income streams of farm families (Figure 15).

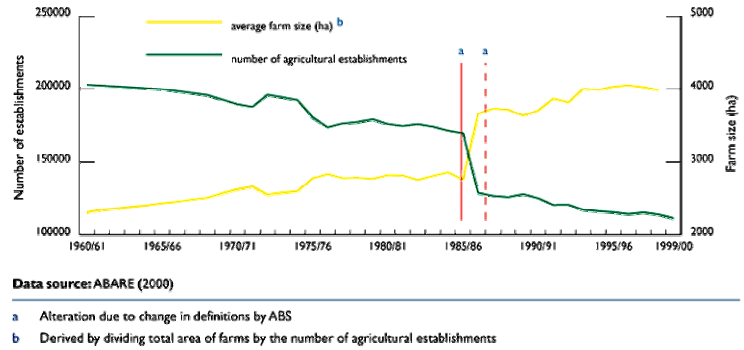

Figure 12. Change in Australian farm numbers and area, 1960 – 2000. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.70)

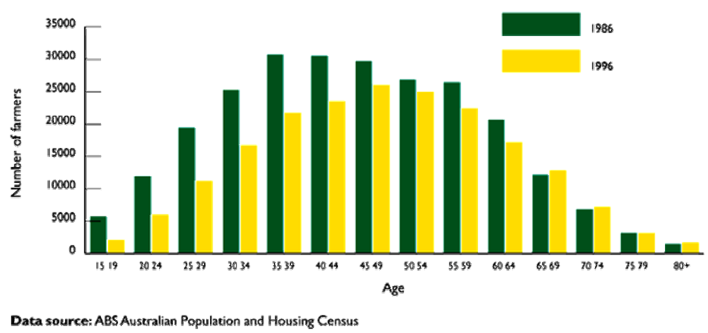

Figure 13. Number of persons with farming as their main occupation by age group, 1986 and 1996. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.75)

Figure 14. Australian farm family income distribution and Australian family income distribution, 1996. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.72)

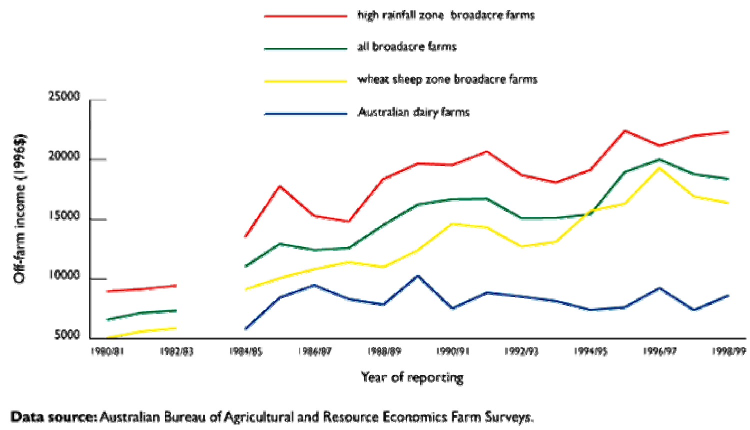

Figure 15. Annual off-farm income earned on Australian broadacre and dairy farms, 1980 to 1998 (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.73)

The condition of the resource base for agriculture

Dryland salinity

It is ironic that even though Australia is such a dry place, it is water excess that is driving one of the most serious threats to agriculture and landscape health. The natural vegetation, with the twin characteristics of perenniality and deep-rootedness, was effective in using most of the rainfall, with only small quantities of runoff and virtually no deep drainage, except in the higher rainfall coastal regions. In these circumstances, water tables were stable and the massive salt stores in the Australian landscape were also stable. Replacement of deep-rooted perennial vegetation with shallow-rooted annual crops and pastures, together with agricultural practices such as fallowing, have resulted in perhaps a ten-fold increase in the water leaking below the root zone of the agricultural systems. The quantities involved are estimated to be in the range 10 to 100 mm/year depending on climate, farming system and soil characteristics (Dunin *et al*., 1999; Stirzaker *et al*., 2000; Asseng *et al*., 2000; Keating *et al*., 2001). These quantities may only represent 5 – 15% of annual rainfall and only a fraction of this extra water will find its way into deep groundwater systems. However, such perturbation of the water balance is sufficient to cause relatively rapid (20 to 50 years) rise in water tables and in many cases, outbreaks of dryland salinity. Areas most affected are located in the MDB and south-west Western Australia (Figure 16). Approximately 4.6 million ha of agricultural land were thought to be at "high risk" of developing dryland salinity in 2000 (Table 2). Model-based estimates suggest this figure could grow to 3 to 4-fold by 2050. Loss of productive agricultural land is not the only impact – there are very significant threats to remnant native ecosystems and build infrastructure also (Table 2).

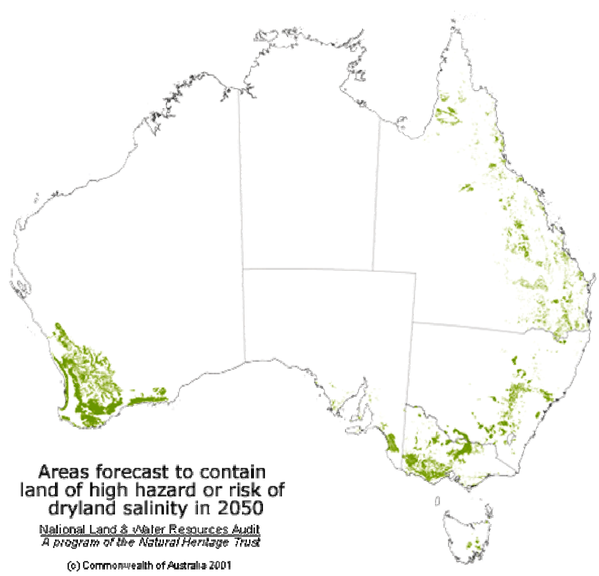

Figure 16. Areas forecast to contain land of high hazard or risk of dryland salinity in 2050. (from NLWRA (2000) "Australian Dryland Salinity Assessment 2000", pp.7)

Table 2. Summary of assets in areas at high risk from shallow watertables or with a high salinity hazard. (from NLWRA (2000) "Australian Dryland Salinity Assessment 2000", pp.8)

Asset	2000	2020	2050
Agricultural land (ha) [1]	4 650 000	6 371 000	13 660 000
Remnant and planted perennial vegetation (ha) [2, 5]	631 000	777 000	2 020 000
Length of streams and lake perimeter (km) [2]	11 800	20 000	41 300
Rail (km)[2]	1 600	2 060	5 100
Roads (km)[2]	19 900	26 600	67 400
Towns (number)[3]	68	125	219
Important wetlands (number) [1, 4]	80	81	130

Notes: [1] Data from all States, Qld only for 2050. [2] Data from WA, SA, Vic and NSW, Qld only for 2050. [3] Data from WA, SA, Vic and NSW. [4] Including Ramsar wetlands. [5] Much of the remnant and perennial vegetation reported for each State occurs on agricultural lands.

While Australia's agricultural landscapes have seen the impacts of shifts in the water balance relatively quickly (eg. 20-100 yrs), the generally old and flat landscapes, with their slow moving surface and groundwater systems are likely to take much longer to reach a new equilibrium. Depending on the nature of the groundwater systems and salt stores, it is likely to take between hundreds and in some cases, thousands of years for the consequences of mobilised salts to be fully realised and for the results of interventions to take effect (Walker *et al*., 1999; Stirzaker *et al*., 2000).

Nutrient balance

Nutrient balances determined at the farm gate highlight important regional and elemental differences. Inputs largely balance or moderately exceed outputs for nitrogen, phosphorus, sulphur and calcium across the southern agricultural areas. In contrast, potassium and magnesium outputs generally exceed inputs to these farming systems and soil reserves are being slowly run-down. Nitrogen and phosphorus inputs to intensive horticultural, diary or sugarcane industries are generally strongly positive, suggesting a risk of excess nutrients being lost to the wider environment. The nutrient balances on the more inherently fertile heavy clay soils of sub-tropical agricultural regions are more likely to be negative, suggesting longer term nutrient mining. An example of farm-gate nutrient balance is shown for nitrogen in Figure 17.

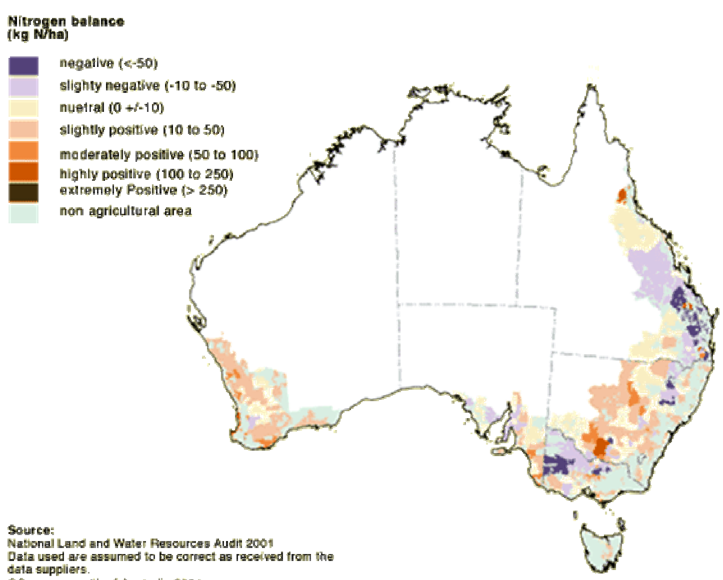

Figure 17. Farm gate nitrogen balance (kgN/ha) for all land uses combined – 1992-1996. (NLWRA (2001) Australian Agriculture Assessment 2001, pp.93)

Increasing nitrogen fertiliser usage has been a major feature of nutrient balances over the last 20 years (Figure 18). A host of factors have driven this trend, including more intensive cereal cropping, growth in canola plantings, improved cereal varieties and rotations that are more responsive to nitrogen inputs, responses to lower protein levels in wheat.

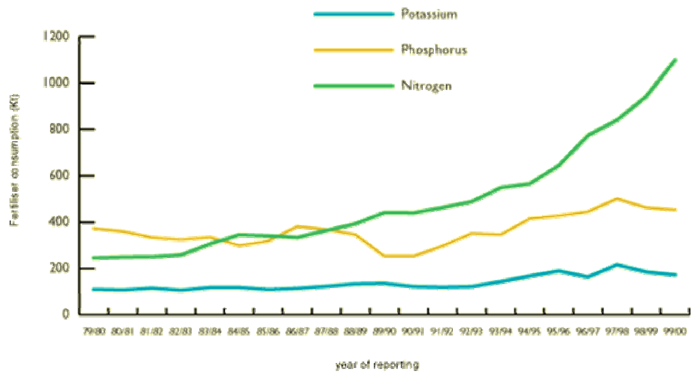

Figure 18. Trends in NPK fertiliser consumption in Australia (1979 – 1999). NLWRA (2001) Australian Agriculture Assessment 2001, pp.84)

<u>Acidification</u>

Agricultural practices and soil and climatic conditions are generally driving acidification processes within Australia's agricultural landscapes. Key drivers include; ammonium based fertiliser inputs, leaching of nitrate from fertilisers or legume fixation and removal of alkalinity through removal of crop and pasture products (Verburg *et al*., 2001). Between 12 and 24 million ha of agricultural land is estimated to have surface soil pH levels less than or equal to 4.8. Distribution of acid top-soils can be seen in the interpolated data derived from commercial soil testing activity (Figure 19).

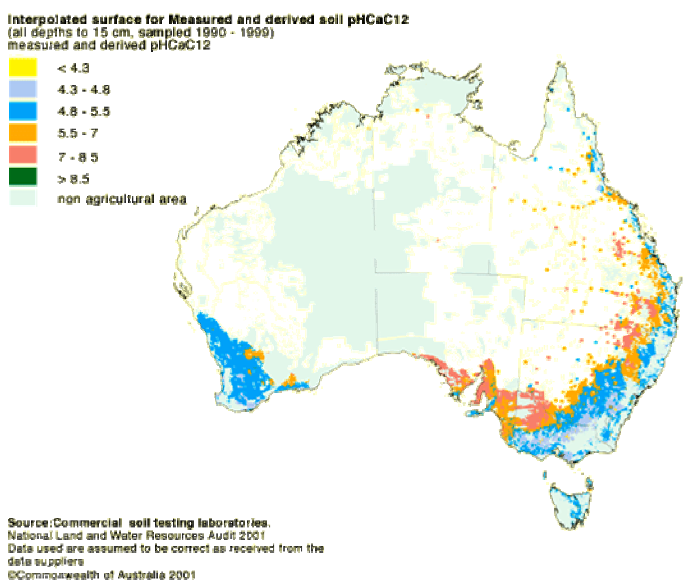

Figure 19. Interpolated topsoil pH, 1990–1999. (NLWRA (2001) Australian Agriculture Assessment 2001, pp.127)

Acidification is an on-going process and this area of limiting surface soil pH for acid-sensitive agricultural plants is likely to increase 2 to 3 fold over the next 10 years. Sub-soil acidity is also a limitation to plant growth with an estimated 5.3 million ha having subsoils with a pH less than 4.8. Whilst about 2 million tonnes of lime are applied to agricultural lands each year, between 12 and 66 million tonnes of lime are estimated as necessary to adjust surface soils to a pH of 4.8 and 5.5 respectively. Further applications would be needed to prevent re-acidification. Acidification is something of an insidious soil degradation issue. The impacts are not seen in the same dramatic way as those of dryland salinity – yet the areas affected are greater. The degradation can be avoided or reversed through management practices, in particular regular lime applications, but the costs are often prohibitive given the relatively low profitability of many agricultural enterprises.

Erosion

Erosion, whether it be via sheetwash, rills or gullies, is a natural process, but its rate and extent has been accelerated with agricultural development since European settlement. This has implications for both agricultural productivity and the environment, the latter through addition of sediments and nutrients to fresh and marine aquatic ecosystems. Sheetwash and rill erosion are estimated to be the dominant soil movement processes, particularly under the higher rainfall intensities of northern Australia (Figure 20). Seasonal loss of vegetative cover is also a major driver of erosion potential. On average, sheetwash and rill erosion has accelerated by a factor of three over the natural rate prior to European settlement, but much greater increases in erosion rate have been estimated for particular land uses or regions.

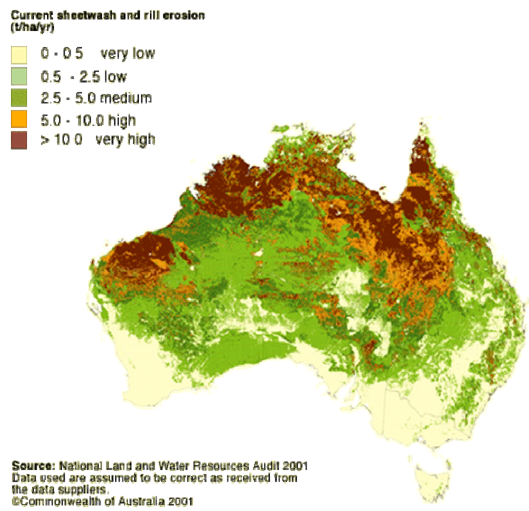

Figure 20. Estimated current sheetwash and rill erosion rate. (NLWRA (2001) Australian Agriculture Assessment 2001, pp.164)

Enhanced gully erosion has also been a major impact of agricultural development – in many cases gullies formed soon after clearing and have now stabilised to some extent. In other cases active new gully formation and sediment delivery to streams is still occurring. Gully density overall has been estimated at 0.13 km km^{-2}, representing 325,000 km of gullies in the regions assessed. Highest densities of gullies are to be found in the sloping lands to the east of the MDB, and in the Burdekin and Fitzroy catchments of Queensland (Figure 21).

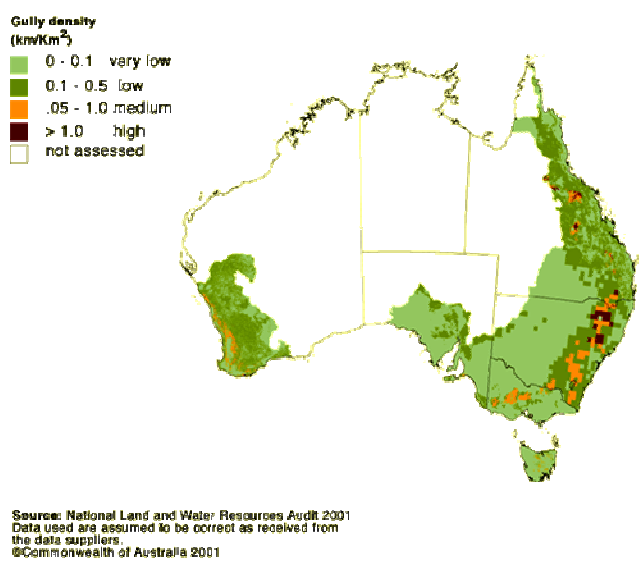

Figure 21. Estimated gully density (km / km2) (NLWRA (2001) Australian Agriculture Assessment 2001, pp.174)

Streambank erosion is a major source of river sediments. Four-fold increases in stream width and a doubling of stream depth are common along cleared creeks and rivers. An estimated 65% of Australia's river and stream length has been cleared of riparian vegetation. This amounts to 120000 km of streams – restoration has been estimated conservatively to cost $1.2 billion (with volunteer labour and aside from any lost agricultural production impacts).

As part of the NLWRA process, model based estimates were made of the extent and fate of sediment loads in Australia's river systems. Sheetwash and rill erosion are estimated to be the major erosion processes in terms of sediment movement but only about 8% of soil loss from hillslopes is estimated to reach the streams and rivers. Within the river systems, sediments from gullies and streambank erosion are comparable in quantity with sediments from sheetwash and rills. Only about 20% of the total sediment load ends up being exported from rivers – the balance is deposition within the rivers, floodplains or in reservoirs (Table 3).

Table 3. Components of sediment supply estimated for Australia (million tonnes/year). (NLWRA (2001) Australian Agriculture Assessment 2001, pp.176)

Gross sheetwash and rill erosion	666*
Delivery to stream from sheetwash and rill erosion	50
Gully erosion	44
Streambank erosion	33
Total sediment supplied to rivers	**127**
Total suspended sediment stored	66
Total bed sediment stored	36
Sediment exported from rivers	25
Total of stores and losses	**127**

Water resources

On a continental scale, 12% of Australia's rainfall runs off into river systems and only 20% of this potentially divertible water is utilised for agricultural, industrial or human activities. These continental averages mask the great diversity in pressure that is currently being placed on Australia's water resources. Almost half of all water flows in Australian rivers runs out to the Timor Sea and the Gulf of Carpentaria from the largely pristine rivers of the northern wet/dry tropics (Figure 22). In contrast, only 6.1% of all runoff is found in the agriculturally very significant Murray-Darling Basin and over half of this runoff is diverted for human and agricultural activities (Figure 22). Not surprisingly, the ecosystems of the MDB are under extreme stress as they compete for water with irrigation industries.

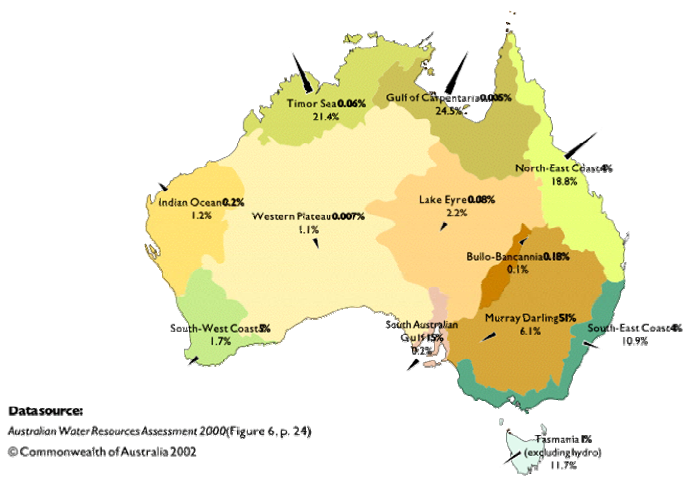

Figure 22. Percent of total Australian runoff from each drainage division. Bold figures after each division caption represent proportion of division diverted for human and agricultural use (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.34)

Surface water flows are close to fully committed or overcommitted, in comparison with best estimates of sustainable flow regimes in 26% of surface water management areas – these over commitments are most pronounced in the MDB (Figure 23). Water quality data coverage is incomplete but more than 33% of basins fail to meet standards for turbidity, salinity and nutrient levels (Figure 24).

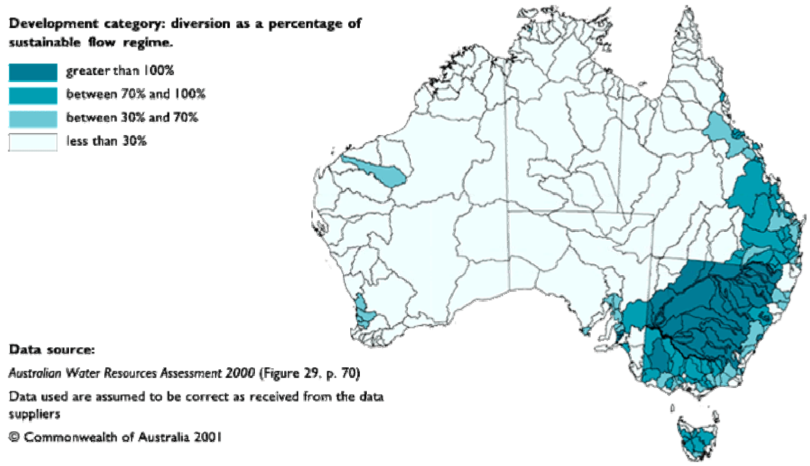

Figure 23. River flow diversions as a proportion of sustainable flow regimes. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.37)

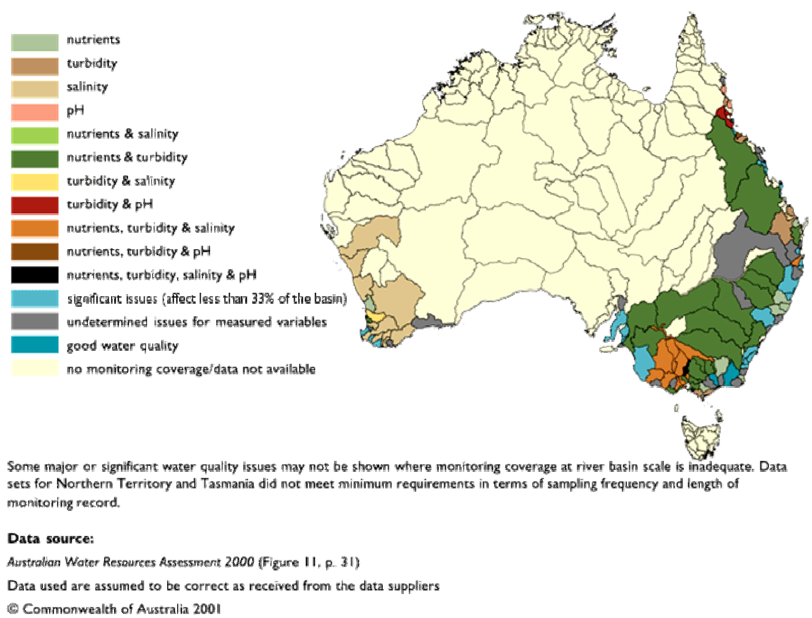

Figure 24. River basins experiencing water quality issues. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp.44)

The condition of the natural environment

Native vegetation

Native vegetation clearing has been concentrated on the more intensive agricultural land use zones and in urban areas (Figure 25). Many agricultural regions have less than 30% of the original native vegetation remaining and often the vegetation that is left is highly fragmented – with implications for ecosystem function and biodiversity protection (Figure 26).

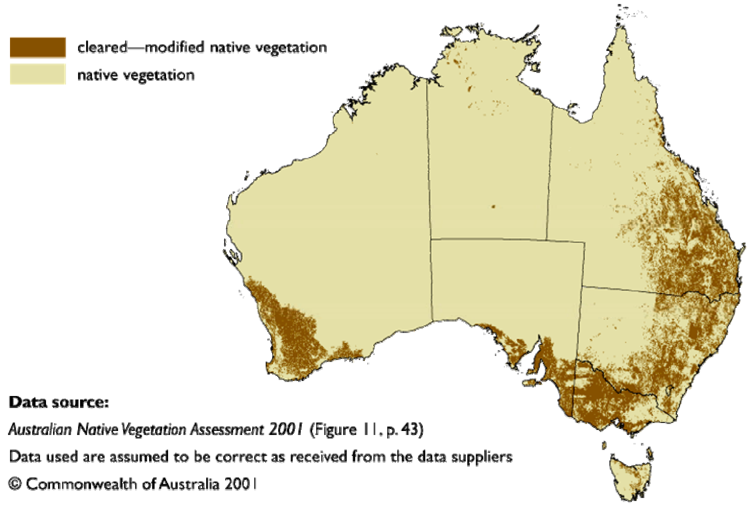

Figure 25. Extent of native vegetation clearing in Australia. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp. 47)

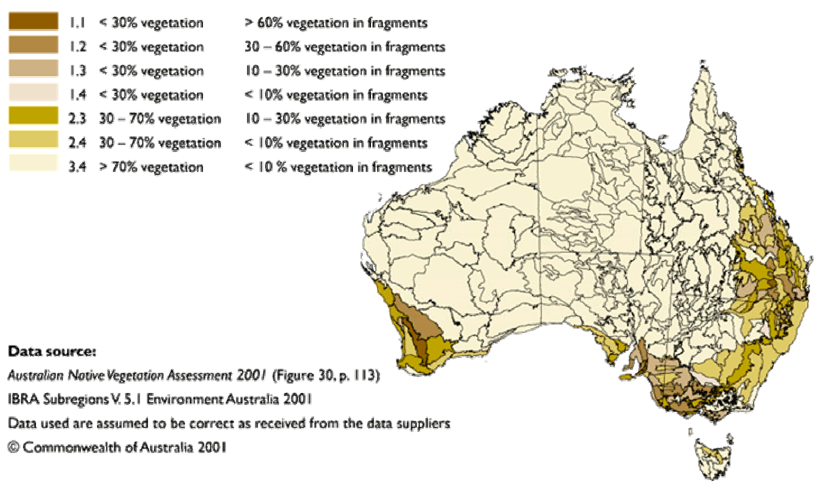

Figure 26. Extent of fragmentation of native vegetation in Australia. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp. 51)

<u>Native mammals and birds</u>

Australia's evolutionary history resulted in a species rich mammal fauna. Eighty five % of 305 indigenous species of mammals are endemic to Australia and of the remainder, the majority are bats shared with New Guinea and nearby islands. This great biological legacy of the break-up of Gondwanaland and 30-40 million years of relative isolation as Australia drifted in the southern seas has come under great pressure since the arrival of Europeans. In the reverse of the situation with native vegetation, the impacts on the native mammal fauna have been greatest in the arid and semi-arid rangelands (Figure 27), with massive restrictions in range for large numbers of mammal species. Overall, 22 species of native mammal have become extinct and another 8 survive only on off-shore islands since the arrival of Europeans. This record represents about one third of the world's recent mammal extinctions. Feral cats, foxes and in some regions canetoads have been the major forces driving small mammal species towards extinction.

The impact of European settlement and agricultural development on Australian native birds has been more evident in massive reductions in range rather than extinction. Within agricultural lands, 29 species of birds have had very significant reductions in occurrence in response to loss and fragmentation of habitat. Grassland, woodland and ground-nesting birds have been most affected (NLWRA, 2002).

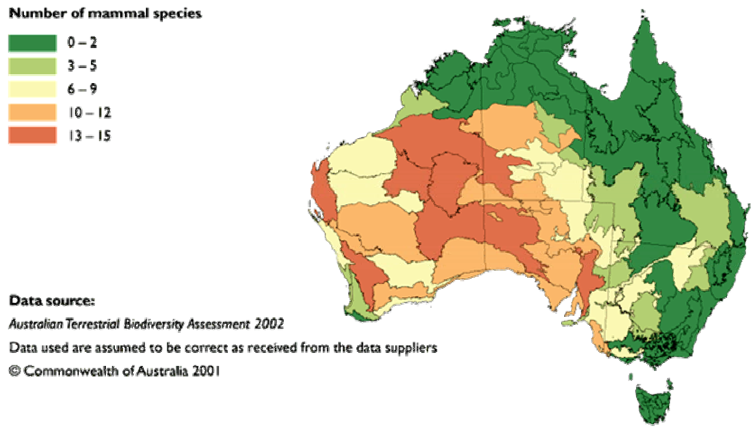

Figure 27. Number of mammal species of the original fauna in each region whose range has contracted from > 90% of the regions originally occupied. (from NLWRA (2002a) "Australia's Natural Resources 1997-2002 and beyond", pp. 56)

Sediments and nutrients in aquatic ecosystems

The NLWRA estimated that 12% of river basins had suspended sediment loads more than 50 times the pre-European settlement loads. Only a fraction of these loads (estimated at 20% on average) is thought to reach estuaries and marine environments. The quantities of sediments exported are highest from the Queensland and to a lesser extent, New South Wales coastal river systems (NLWRA, 2001). NLWRA estimated that an average of 19000 tonnes of P and 141000 tonnes of N are exported via rivers to the coast each year. Highest export rates were from Queensland and New South Wales coastal river systems, although in some cases (such as in the southern Queensland / Moreton Bay region, urban point sources made significant contributions (eg. 31% of the total P load for Moreton Bay is estimated to come from urban sources).

Catchment condition

Condition assessment is an important part of setting benchmarks and priorities for NRM investment and intervention. The NLWRA deployed an assessment framework based on land, water and biota elements (Figure 28). Key indicators used to assess these elements are given in Table 4.

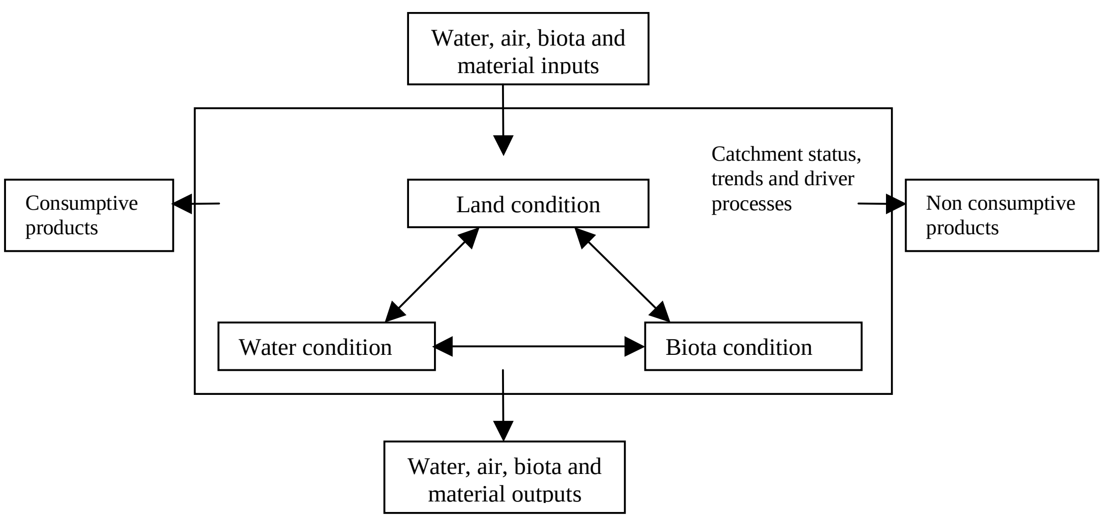

Figure 28. Model of catchment condition used in the assessment framework of the National Land and Water Resources Audit. (from NLWRA (2002b) "Australian Catchment, River and Estuary Assessment", pp. 27)

Table 4. Indicators used to define the water, land and biota subindices and the catchment condition index. (from NLWRA (2002b) "Australian Catchment, River and Estuary Assessment 2002", pp. 29

Indicators	Related catchment management issue
Water	
Suspended sediment load	Modelled post-settlement change in suspended sediment loads
Pesticide hazard	Pesticide use is a surrogate for pesticide pollution risk
Industrial point source hazard	Industrial pollution contamination risk
Nutrient point source hazard	Nutrient point source loading of waterways
Impoundment density	Ecosystem changes associated with altered flows
Land	
2050 high dryland salinity risk/hazard	Modelled risk assessment of salinity impacts
Soil degradation hazard	Soil and land use assessment of soil degradation risk
Hill slope erosion ratio	Modelled assessment of changes in hill slope erosion potential from natural conditions
Biota	
Native vegetation fragmentation	Deterioration in native habitat
Native vegetation extent	Habitat quantity and distribution
Protected areas	How much habitat is protected
Road density	Human population and land use intensity pressures
Feral animal density	Extent feral animals have impacted on native biota
Weed density	Extent of disturbance to native vegetation

When a composite catchment condition index is developed based on the indicators in Table 4, and the results mapped at sub-catchment scale, regions of poor catchment condition are identified (Figure 29) and seen to align in broad terms with;

- the wheat-sheep belt and coastal agricultural areas of Western Australia
- western and central Victoria and cropping zone of South Australia
- the western slopes and plains of New South Wales
- the north-east MDB in southern Queensland
- cropping regions of central Queensland
- coastal floodplains of Queensland and northern New South Wales.

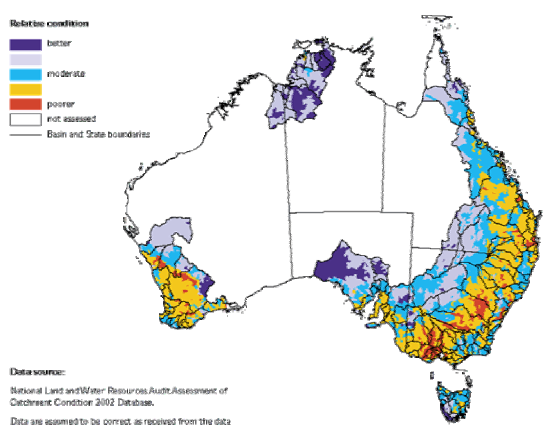

Figure 29. Relative catchment condition (in 500 km^2 grid cells) based on the model in Figure 28 and indicators in Table 4. (from NLWRA (2002b) "Australian Catchment, River and Estuary Assessment 2002", pp. 36)

Australian Agricultural Futures in the 21st Century.

The NLWRA has clearly demonstrated that agricultural development in Australia, while delivering both economic and social benefits in the past and present day, has come at a significant cost to the resource base and wider natural environment. In this section we take stock of the insights arising from the NLWRA and reflect on the key emerging issues of Australian agriculture in the 21st Century.

Evolving views on the role for agriculture

In 2004, we find an Australian agriculture that is increasingly challenged on its identity and purpose. In 1788, the first European farmers enabled the colony to survive by supplementing the shipment of supplies from England. In the 19th Century, the frontiers were being pushed back, the land was tamed and great wealth was generated on the export of commodities to a rapidly industrializing old world. Science and innovation solved problems that allowed new lands to come under the plough. While discoveries of gold and other minerals came and went and had their own dramatic impact, agriculture was unambiguous in its purpose and still dominated the economy.

This situation persisted for at least half the 20th Century, but the latter part of that Century saw a dramatic decline in the significance of agriculture in the economy. Alongside this we saw loss of traditional markets in Europe, development of new markets in Asia and the Middle East, relentless decline in terms of trade for commodity based agriculture, and an equally relentless search for efficiency gains and industry restructure to remain economically competitive (in terms of global markets). The "get big or get out" phenomenon has been a major driver of change in Australian agriculture for the last 50 years. In 2004, the "profitable" footprint of Australian agriculture is very small, when assessed in full equity accounting terms. Access to irrigation waters (at costs below real market values) has played a major part in some industries and regions remaining profitable. Increasingly we see heightened competition within and between regions, industry sectors and between production and environmental uses of such water resources (eg. Colebatch, 2004). Competition for essential resources such as irrigation water has become the new frontier for Australian agriculture in the 21st Century, replacing the "taming the bush" frontier of the 19th Century.

Another present day "frontier" for Australian agriculture is also to be found in the peri-urban and coastal regions where agriculture is struggling to compete with urban and amenity land uses for lands with soils of a quality suited to farming (Kelleher, 2001). These social and economic forces shaping change in rural landscapes are not just confined to the peri-urban and coastal regions. In Victoria, "amenity" or lifestyle farming is common in landscapes that were once the heartland of the State's agriculture (Reid *et al*., 2003; Barr, 2003). While farming still persists in these landscapes, it is supported by off-farm income and/or is diversifying to post-production activity such as agri-tourism.

While agriculture is likely to remain profitable in locations and circumstances where resources, markets, management and innovation allow, we expect to increasingly see Australian society valuing the "non-production" aspects of agriculture (i.e. agro-ecosystem services such as clean water supplies, greenhouse gas abatement, catchment management, flora and fauna conservation, heritage preservation, indigenous land use, open space and amenity values). Such non-production or "consumption" aspects of multifunctional agricultural landscapes appear well recognised in Europe (Baldock *et al*., 2001; Bohnet *et al*., 2003), but are only just beginning to receive attention in Australia (Holmes, 2002). The rise in the significance of ecosystem services and consumption values of agricultural landscapes represents a significant challenge to our policies and institutions which have evolved under a traditional production view of agriculture.

Climate change impacts

Any writing on the future of agriculture in Australia would be remiss not to flag the potential for greenhouse induced climate change to have significant impacts over the next 50-100 years. World climate model forecasts suggest higher temperatures and both increases and decreases in rainfall for Australia's agricultural areas over these time periods arising from greenhouse induced climate change (Figures 30, 31) (CSIRO, 2001). While the uncertainties in these scenarios are very large, we are already seeing well established warming trends across most part of the continent, and long-term declines in rainfall (Suppiah *et al*., 2001) in some regions (such as south-west Western Australia and eastern Australia) - the degree to which such changes can be put down to greenhouse influences remains uncertain. While controversial, the severity of the 2002 drought in Australia is thought by some to have been increased by the higher evaporation associated with higher temperature (ie. 1.6°C anomaly for average temperatures in the MDB during the March-November 2002 period) (see Karoly *et al*., 2003). As discussed earlier, Australia has seen many major shifts in climate over geological time scales, but there is a real prospect we are going to see unprecedented rates of change in our climate – at a time when natural ecosystems and agricultural systems are already under multiple pressures from resource degradation.

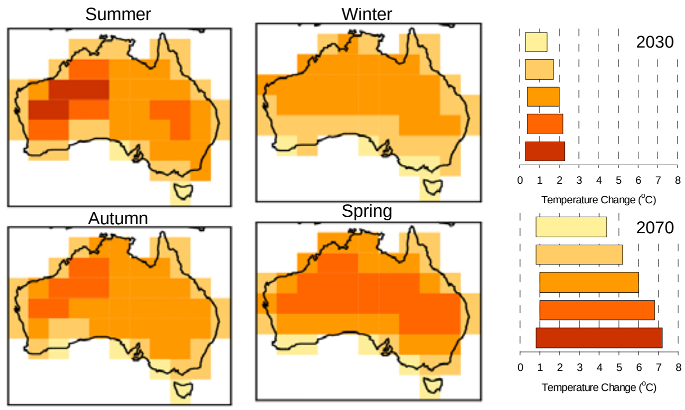

Figure 30. Climate change scenarios for Australia – predicted mean annual temperature change 2030 –2070 (CSIRO, 2001)

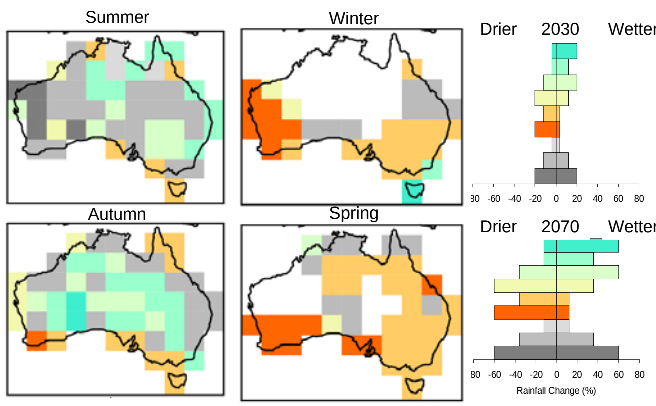

Figure 31. Climate change scenarios for Australia – predicted mean annual rainfall change 2030 –2070 (CSIRO, 2001)

Changing resource base

The resource base for agriculture has been degraded to varying degrees. Some lands have been lost totally (for example to salinity), and while dramatic, the economic significance of these losses is small as production shifts or intensifies (and as farm amalgamations continue). Less dramatic but economically more significant losses in productivity are associated with soil degradation (acidification, organic matter rundown, soil compaction, soil biology disruption). The environmental legacy of 200 years of agricultural development is also very significant. The nation's human and built capital has grown out of primary production (initially dominated by agriculture), but the costs to Australia's unique natural capital are large and ongoing. For instance, salinisation in Australia's agricultural landscapes has been as much a tragedy for the natural environment as it has been for agriculture (eg. Ive and Nichols, 2000; Briggs and Taws, 2003)

Looking forward, agriculture, while only a small part of the Australian economy, will remain the primary land use on the arable lands. Continuing efficiency gains, through both technical innovation and farm amalgamations to drive economies of scale, will be essential to maintain profitability in most enterprises. The need for agricultural activities better adapted to the Australian environment remains. In particular systems that restrict leakage of water and nutrients to rivers and groundwaters are urgently required. The magnitude of the challenge to find enterprises or management systems that are competitive in terms of profitability and protect the resource base cannot be underestimated. At present, no economically attractive perennial options are available for the majority of the land affected by dryland salinity (Bathgate and Pannell, 2002) and the economically logical course of action in many salinising landscapes is to right off 10 – 20% of the landscape to salinity and maintain more profitable but leaky systems on the balance of the farm. This logic is from the narrow perspective of an individual producer – a broader view that includes consideration of costs to the environment or public infrastructure might lead to different conclusions.

Key themes for agriculture and natural resource management in 21st century
Regardless of the economic and social drivers for future agriculture, the marriage of scientific and practical knowledge will remain fundamental on this journey towards sustainability. Key current or emerging themes that are calling upon scientific knowledge to be connected with practical, adaptive management activity include:

- public participation towards enhanced natural resource management (eg. Landcare) (Campbell, 1994; Curtis, 2003; Cullen *et al*., 2003),
- new forms of national and regional governance of natural resource management, currently evolving in Australia through programs like the National Action Plan for Salinity and Water Quality (COAG, 2000) and the Natural Heritage Trust (NHT, 2004). Such national experiments in governance and delivery of natural resource management, with their strong focus on decentralised regionalism, are still in their early formative stages and have many challenges ahead (see Lane *et al*., 2004 for a discussion of some of these challenges),
- reform with respect to key natural resource management issues (eg. COAG Water Reform, COAG, 1994)
- novel farming systems better adapted to the Australian environment (eg. bioenergy, mosaic farming/precision agriculture, Australian native plant species) (Higgins and Portelli, 1998; Williams, 1999; Lefroy, 2001; Cooper *et al*., 2004),
- Environmental Management Systems (EMS) or related approaches to quality assurance in all aspects of farm business operation (see Ridley 2001 for an overview relevant to Australia),
- recognition, valuing and enhancing the beneficial services that ecosystems (including agro-ecosystems) can provide outside of traditional production perspectives (Cork *et al*., 2002; Abel *et al*., 2003), and
- new market based approaches and instruments (Bardsley, 2003) to achieve policy goals eg. water trading (NRMSC, 2001); bush tender (Stoneham *et al*., 2003).

All these themes are fundamentally dependant on both a scientific underpinning in terms of ecosystem function and agricultural technology and a practical perspective in terms of “on the ground” change in practice. This dynamic between theory and practice is now central to scientific endeavour and natural resource management in this country (Campbell, 2004; McCown, 2001, 2002).

Reflections on Natural History
It is a sad realisation that the model of sustainability provided by indigenous cultures and honed over 40-60 thousand years of changing climate, biology and landscapes was lost on the European arrivals in the late 18th Century. Survival was the initial primary objective and then wealth creation - both objectives seen through European eyes coming to grips with a very different landscape. It took over 200 years for the Australian political and legal system to recognise some form of indigenous prior ownership of these lands (Parliament of Australia Library, 1993). Sustainable land management practices fitting for an indigenous culture in 1788 are clearly not directly transferable to a nation of 20 million people in 2004. But some sense of the aboriginal relationship to “country” remains as relevant in Australia in the 21st Century as it has over the last 40-60000 years.

This is a special place – it has a geological history stretching back over 600 million years, a biological history uniquely fashioned out of 30-40 million years of isolated evolution and a human history perhaps as long as 60,000 years. In 200 years the “new Australians” have achieved great things, and agriculture has laid the foundations of much of this achievement. But the costs to the natural resource base and environment have also been great. The future of this place lies in rethinking the relationships between people, the land and its ecosystems. Combining scientific and practical knowledge in the pursuit of sustainable land management is as large a challenge for Australia in the 21st Century as was the establishment of agriculture and the “taming of the bush” in the 19th Century.

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