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Australia's Soil Salinity – a man-made modern Plague

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Preface



Photo by author, 2001

At the end of the twentieth and the beginning of the twenty-first century salinisation of land and water has become one of the most critical environmental problems Australia is facing.

Australia, a land with big potentials, great bio-diversity and a unique flora and fauna, today has to deal with quite a few human induced problems, some of them caused by the uncontrolled rigorous clearing of native bushland and forests for agriculture. Combined with irrigation, exploitation of soils and resources and the introduction of European annual crops, grasses and other plant material which are not adapted to the harsh Australian environment, this led to a big upset in the delicate natural balance. The leakage of rain and irrigation water is much greater under current agricultural systems than under natural vegetation. It occurs when the plant/soil system cannot cope with the amount of water falling over a period of time. The consequences are rising groundwater levels, which carry the salt to the surface where it is discharged leaving barren unusable land behind. The area threatened and already affected by salinity covers about 4.5 per cent of present cultivated land, which amounts to approximately 2.5 million hectares of arable land. Unfortunately there is the potential for this to increase to 15 million hectares and more in the near future. Much of it is Australia's most productive agricultural land. Dryland salinity is spreading and appears where it has not been seen before, (ABS, 2008). The costs of the damage caused by salinity runs into millions of dollars. The annual loss in agricultural production exceeds \$ 130 million, the damage to infrastructure over \$ 100 million, and at least \$ 40 million worth is the loss of environmental assets (if one can put a dollar value to that at all (ABS, 2008).

Salt is also seeping into rivers, streams and lakes and into groundwater systems, making the water unusable for human consumption in some of the worst affected areas. It not only attacks

farmland but also spreads to urban areas where it is destroying the infrastructure. To counteract this process and to try to reduce the extent of salinity, very costly preventative measures have to be taken: drainage, change in agricultural cultivation, reforestation, planting of salt resistant vegetation, combined with a complete change of attitude towards the environment. The thoughtless interference with the natural surroundings without consideration for possible after-effects proves here again that one should not tamper with nature!

Aims of this Paper

In this paper the fragility of nature and some severe results of interfering with and destroying of native vegetation and the introduction of foreign flora is being discussed. The background, the causes, effects and implications of salinity are described as well as the options and practices for controlling and adapting to salinity. The origins of the salt in the natural environment, the causes of salinity and the extent of the areas at risk are explained as well as the effects of salinity on water resources (streams, rivers and groundwater), on natural diversity (physical and biological), on agricultural lands, on infrastructure and rural communities. The fundamental cause of salinity, the clearing of land and the replacement of native deep-rooted perennial vegetation with annual crops and pastures used in agriculture, should stand out clearly. For annual crops and pastures do not use as much of the rainfall as the native vegetation did before. This unused water is filling up the groundwater systems which causes a rise in the water-tables, and areas of groundwater discharge and soil salinity are expanding.

There is no easy solution to the salinity problem. Especially since salinisation is a long-term process. If unmanaged, it will eventually reach a new equilibrium as recharge to groundwater systems is balanced by discharge from them. Then groundwater will stop rising and the spread of soil salinity will cease. The time required reaching such an equilibrium may range from as little as ten years in the high rainfall areas to more than 200 years in the drier regions. Surface and near surface saturation is escalating the risk of erosion and land degradation. These potential impacts are too serious to ignore.

Commonwealth and State Governments with their various Departments (Agriculture, Conservation and Land Management, Environmental Protection, Water and Rivers Commission, etc.) have and still are investing in numerous research projects and programs, to develop salinity management practices – options that will have a positive effect on salinity and minimize its impact. But nothing will be achieved unless there is action on the ground to implement the appropriate treatments in every salt-prone area of Australia.

Introduction



www.mapofworld.com

Australia is one of the most biologically precious places on earth, with a wonderful array of flora and fauna, much of which is unique to this country. Internationally the World Wildlife Fund has identified the Global 200, – 200 regions that together represent the world’s most vital and significant bio-diversity. It is a symbol of Australia’s incredible wealth and preciousness that 12 of the Global 200 exist here. These 12 eco-regions range from the Great Barrier Reef, through to the Great Australian Bight – home of the sea-lion and a breeding ground for the southern right whale (www.worldwildlife.org).

The unique flora and fauna of Australia results from its geographic isolation brought about by its geological history. In pre-Tertiary times Australia shared much of its flora and fauna with other parts of the super-continent Gondwanaland and in the Mesozoic had a population of dinosaurs comparable with that of other continents. After the break-up of Gondwanaland (probably as recently as the Jurassic) a distinctive and characteristic flora and fauna developed

in Australia, including many of the native plants and animals which differ markedly from those of other countries. The most prominent and widespread of the essentially Australian elements are the Eucalyptus and the Acacias as well as the Marsupials. But unfortunately after two centuries of European occupation the vegetation and wildlife have been modified in many places (right up to extinction and eradication) (Jeans, 1986).

Before European settlement the plant cover and natural fauna could be regarded as an approximation to the original habitat. Human influence was limited to the hunting and gathering activities of the sparse Aboriginal population. The Aborigines undoubtedly modified the vegetation to some extent by the use of fire; but fires caused by lightning are after all part of the natural environment of Australia. Whatever may have been the influence of Aboriginal man, in any case it must have been minor in comparison with later European disturbance.

Today much of Australia's bio-diversity is under threat. Australia is one of the leading over-consumers of resources in the world, with per capita levels of carbon dioxide emissions, a principal cause of global climate change, four times the world average. Australia also leads the world in having the most threatened reptiles and amphibians. Sadly we already have "won" the extinction race, with 50% of all of the mammal losses in the last 200 years having occurred in Australia (www.biodiversity.csiro.au).

Thus together with the arrival of the white man came a sudden breakdown in biotic isolation. The behaviour of naturalized compared to native plants suggests that geomorphic history is important especially as it affects natural soil nutrient levels. However clearing, burning, hunting, agriculture, induced erosion, application of fertilizers and the introduction of exotic non endemic plants and animals have utterly altered the Australian scene, which perhaps has changed more in the last 200 years than in the previous 200 million.

Therefore we can isolate the main culprits that are threatening and destroying Australia's uniqueness and its unequalled bio-diverse regions. One of them being deforestation, clearing woodlands for farming and housing, which is still an ongoing factor in Australia's agriculture, despite trials to conserve land and native vegetation (www.anra.gov.au).

Overgrazing of pastures and allowing stock to invade native bush and woodlands, another result of inappropriate agricultural systems, threatens vegetation by preventing the regeneration of native plants, that can eventually lead to their extinction.

Another problem present introduced pests and weeds, which endanger the survival of many of the regions' ecosystems and species. Major invasions change the natural diversity and balance of ecological communities. These changes threaten the survival of many plants and animals; weeds compete with native plants for space, nutrients and sunlight.

Many coastal environments, particular near large cities, have been degraded by excessive coastal developments and their resulting pollution from the land. Over-fishing and some shipping activities are also a threat to these sensitive regions (www.environment.gov.au).

Vast mining activities also present a threat to eco-regions. It can lead to heavy metal pollution especially in wetlands, affecting its plant and animal species.

The introduction of feral animals into Australia over the last two centuries is one of the biggest problems this country has to deal with. The partly uncontrollable population-explosion of these animals threaten native flora and fauna by competing with them for their habitat, totally eradicating them in some areas. They also present a big pest for agriculture and the farming industry.

Some figures to show the extent of today's feral animal population: 220 million cane toads, 2 million camels, 23 million feral pigs, 5 million donkeys, countless millions of foxes, cats, European rabbits, goats, water buffaloes, horses and wild dogs; - even though in 1859 only 12 rabbits were released into the wild, and in 1935 only 100 cane toads were introduced into Queensland's cane fields!!!! (www.environment.gov.au)

Salinity, the key issue being discussed in this paper, is one of the most severe problems Australia has to face. The main causes of salinisation are the clearing of vast land areas, the indiscriminate chopping down of native forests and woodlands to make room for agricultural land, and the planting of introduced crops and pastures. Now it is rapidly turning large areas of farm- and non-farmland into barren salt wastes, thus becoming one of Australia's biggest environmental hazards.

The evolution of Australian scenery took hundreds of million of years, and the time-scale of landform development is the same as the time-scales of biological evolution and continental drift. To change this scenery it only took about 200 years of European “occupation” of this continent. Unfortunately the change was not for the better, as one would have hoped, but for the worse. The uniqueness of Australia’s environment was never taken into consideration when the first white settlers came to this country. It took almost 200 years, right to the present time, for governments to realize the vulnerability of Australia’s ecology. Unfortunately in the meantime so much had been altered, destroyed and made extinct, that now it will take huge efforts and unimaginable sums of money to try to undo some of the damage.

Colonization

1. The Australian continent was first invaded about 45 - 42 000 years ago by the Aborigines, entering the country from the north. They have lived in this part of the world as hunters and gatherers ever since, or at least up to the time the first European settlers reached the southern continent, terra australis. For the Aborigines every area in Australia was capable of supporting some level of population.

2. By contrast when Europeans first arrived they declared large tracts to be virtually uninhabitable, assessing the environment with quite different eyes than the natives and some land that Aborigines saw as dependable was judged to be a desert by Europeans. It is estimated that some 300 000 (?) Aborigines were sparsely settled throughout the continent in 1788 when the First Fleet from Great Britain arrived in Sydney Cove with convicted small criminals (Encyclopaedia Britannica, 2008; Jeans, 1986).

Few countries have depended on immigration for their very existence, as well as for their growth, to quite the same extent as Australia. After a slow beginning the non-Aboriginal population exploded with the mid-century gold rushes and surpassed one million in 1858 and continued growing until 1890. After economic depressions, various droughts and two World Wars, Australia’s new high birth rates coupled with low death rates and the government’s assisted passage scheme for immigrants, led to a high rate of natural increase, putting more and more pressure onto the fragile natural environment. Today Australia has a growth rate of 1,1%, a population density of 2,4 persons per square kilometres (even though about 85% live in urban areas) and a population of 21,5 million (ABS, 2008).

From the very beginning of European settlement we notice a slow change in the natural flora and fauna. The white man discloses a totally different attitude towards his environment than the native Aborigines. To house and feed the fast growing population wide areas of native bushland was cleared, non endemic imported crops were planted, domestic animals imported, mineral wealth exploited (right until today), - without any consideration for whatever long-term consequences might arise as will be seen in this paper.

1. Physiographic Outline

With its land area of 8.5 million square kilometres, Australia is the smallest of the continents, less than a fifth of the size of Asia. Even if brought to its true continental dimensions by including the continental shelf – and Australia has proportionately the largest continental shelf of all – it still remains less than Antarctica and surpasses only Europe.

Australia is the lowest of the continents, whether measured by the altitude of its highest point, Mt Kosciuszko (2228 m), or by its mean continental altitude of 330 m (www.science.org.au).

Australia is primarily a land of plateaus at low and medium altitudes, and only secondarily of low plains. It is the flattest and (apart from Antarctica) the driest of the continents. Unlike Europe and North America, where much of the landscape dates back to 20 000 years ago (when great ice sheets retreated), the age of landforms in Australia is generally measured in many millions of years. Therefore the land surface has been subjected to millenia of weathering and erosion and only minimal uplift. Consequently it is a land of low relief dominated by plains and low tablelands. This fact gives Australia a very distinctive physical geography (www.anra.gov.au).

The monotony of the flat Australian landscapes is almost unparalleled: to travel hundreds of kilometers without significant changes in landform is commonplace.

1.1. Physiographic Regions



Fig.1, www.harpercollege.edu

As seen in Fig.1 the Australian continent can be divided into three parts – the Western Plateau, accounting for three –fifths of the total area of the continent and containing much of Australia’s mineral wealth, the Central Interior Lowlands and the Eastern Highlands.

1.1.1. Western Plateau

The Western Plateau with its mostly low relief consists of very old bedrock (some over 3000 million years old), and much of it has existed as a landmass for over 500 million years. Several parts have individual ‘plateau’ names (e.g. Kimberley, Hamersley, Arnhem Land, Yilgarn). It also includes the Great Victoria and Sandy Deserts (Wopfner, 1997).

Much of the centre of Australia is flat, but there are numerous ranges (e.g. Macdonnell, Musgrave) and some individual mountains of which Uluru (Ayers Rock) is the best known. Faulting and folding in this area took place long ago, the area was worn to a plain, the plain uplifted and then eroded to form the modern ranges on today’s plain. Looking at Ayers Rock

and the neighbouring Olgas, it is quite remarkable how much softer rock has been eroded from all around, leaving the hard cores behind (Ollier, 1988; Johnson, 2004).

The Nullarbor Plain is virtually an uplifted seafloor, a limestone plain of Miocene age (about 25 million years).

In the Perth area, younger substratum along a coastal strip is separated from the rest by the Darling Fault escarpment.

Parts of the southern Yilgarn district north of Perth and the biggest part of the low lying (below 300m) southwestern corner of Western Australia are prone to salinisation, as pointed out further back (Johnson, 2004).

1.1.2. Central Lowlands

The Central Lowlands with their low relief stretch from the Gulf of Carpentaria in the north through the Great Artesian Basin to the Murray-Darling Plains and the Great Australian Bight in the south. They comprise four main basins of Mesozoic and Tertiary sediments. The Carpentaria Basin, the Lake Eyre Basin, falling beyond sea-level, the Great Artesian Basin, which is filled with sedimentary rocks holding water that enters in the wetter Eastern Uplands and the Murray Basin with the continent's predominant river system, the Murray-Darling, containing the biggest irrigated areas. In the low lying basins, especially in the Murray Basin, the threat of salinisation is prevalent (Ollier, 1988).

1.1.3. Eastern Highlands

The Eastern Highlands or Uplands, the so-called Great Dividing Range rise gently from central Australia towards a series of high plateaus, and even the highest part around Mt. Kosciuszko (2228 m) is part of a plateau. There are a few younger faults and folds, such as the Lake George Fault near Canberra, and the Lapstone Monocline near Sydney. The Great Divide stretches along the coast from Cape York Peninsula to the far southeast and continues into Tasmania (Jeans, 1986).

Some plateaus in the Eastern Highlands are dissected by erosion into rugged hills, and the eastern edges of plateaus tend to form high escarpments. Many of these are united to form a Great Escarpment that runs from northern Queensland to the Victorian border. Australia's

highest waterfalls (Wollombi on the Macleay, Wallaman Falls on a tributary of the Herbert, Barron Falls near Cairns, and Wentworth Falls in the Blue Mountains) all occur where rivers flow over the Great Escarpment. For most of its length the Great Divide (separating rivers flowing to Central Australia from rivers flowing to the Pacific) runs across remarkably flat country dotted with lakes and airstrips, and there is no 'Great Dividing Range'. In eastern Victoria, however, the old plateau has been eroded into separate High Plains (such as Dargo Hill Plain), mostly lying south of the Divide which here runs across rugged country (Johnson, 2004).

Variety is brought into the Australian relief more by dissection of uplifted level surfaces than in any other way. "Mountains of circumdenudation" carved out by the dissection of plateau margins are the most common mountain types in this continent. Upland skylines are mainly subdued and the most impressive relief features are the deep V-shaped valleys and gorges cut below (Jeans, 1986).

In a world view Australia is aseismic, although dislocation along the Meckering Fault in Western Australia in the earthquake of October 1968 was a sharp, if minor reminder that no part of the continent, not even its ancient granitic shield nucleus can be regarded as absolutely stable. However it is true that the continent is lacking in major neotectonics, and we find here no landforms expressing youthful rifting, faulting or folding on a large scale.

A lack of earthquakes goes with a lack of active volcanoes, and Australia is the only continent to be without present volcanic activity (the last volcanic eruption- Mt. Gambier - took place 1400 years ago) (Wopfner, 1997).

1.2. Topography

The present topography results from a long landscape history. In the Permian time, about 290 million years ago, much of Australia was glaciated by a huge ice cap. After the ice melted, parts of the continent subsided and were covered by sediments to form sedimentary basins such as the Great Artesian Basin. By early Cretaceous times, about 140 million years ago, Australia was already so flat and low that a major rise in sea level divided it into three landmasses as the shallow Cretaceous sea spread over the land (Jeans, 1986; Wopfner, 1997). Salt deposits from those inland seas remained in the bedrock for millions of years until today.

In the following Tertiary times Australia can be regarded as a landscape of broad swells, varied by a number of sedimentary basins (Murray, Gippsland, Eucla, Carpentaria, Lake Eyre and other basins). These slowly filled up and some are now sources of coal or oil. The Eastern Highlands uplifted about that time.

Throughout the Tertiary period, volcanoes erupted in eastern Australia. Some individual volcanoes were the size of modern Vesuvius, and huge lava plains covered large areas. Volcanic activity continued up to a few thousand years ago in Victoria and Queensland. Australia's youngest mainland volcano is Mt. Gambier in South Australia, about 6000 years old. Big Ben on Heard Island (far south of the Australian mainland, approaching Antarctica) was active as recently as 1987 (www.geologynet.com).

Between about 55 and 10 million years ago Australia drifted across the surface of the earth as a plate, moving north from a position once adjacent to Antarctica (both once part of the great southern continent Gondwanaland).

The past few million years were notable for the Quaternary ice age. There were many glacial and interglacial periods during this time (over 20). Sea levels rose and fell but Australia remained almost untouched and unchanged, only the shoreline extended and withdrew with the changing sea levels. At the height of the last glaciation on the northern hemisphere in Australia there only is evidence of one small ice shield which covered about 25 square kilometers in the vicinity of Mt. Kosciusko (Wopfner, 1997).

During this last ice age, the sea level was over 100 metres lower than it is today, and rivers cut down to this lower level. When the sea level rose again the lower valleys were drowned. Some are now good harbours (e.g. Sydney Harbour), whilst others have tended to fill with alluvium, making the typical lowland valleys around the Australian coast.

Coastal geomorphology is also largely the result of the accumulation of sediments on drowned coasts. In some areas, such as Ninety Mile Beach (Victoria) or the Coorong (South Australia), there are simple accumulation beaches. In much of the east there is a characteristic alternation of rocky headland and long beaches, backed by plains filled with river and marine sediments (Johnson, 2004).

The offshore shape of Australia, revealed in isobar contours, results mainly from the pattern of break-up of the super-continent of which Australia was once a part. There is a broad continental shelf around most of Australia, bounded by a steeper continental slope, except in New South Wales where the continental shelf is very narrow. The Queensland coast is bounded by a broad plateau; on which the Great Barrier Reef has grown in only the last two million years. In South Australia the continental shelf is grooved by submarine canyons (Ollier, 1998).

The Australian landforms of today are thus seen as the result of long-continued processes in a unique setting, giving rise to typical Australian landscapes, which in turn provide the physical basis for the distribution and nature of biological and human activity in Australia.

Many of Australia's rivers drain inland, and while they may be eroding their valleys near their highland sources, their lower courses are filling up with alluvium, and the rivers often end up in salt lakes which are dry for most of the time. Other rivers reach the sea and have dissected a broad near-coast region into plateaus, hills and valleys. Many of the features of the drainage pattern of Australia have a very long history, and some individual valleys have maintained their position for hundreds of millions of years. The salt lakes of the Yilgarn Plateau in Western Australia are the remnants of a drainage pattern that was active before continental drift separated Australia from Antarctica and the rest of Gondwanaland (Johnson, 2004).

1.3. Australia's Geological Structure

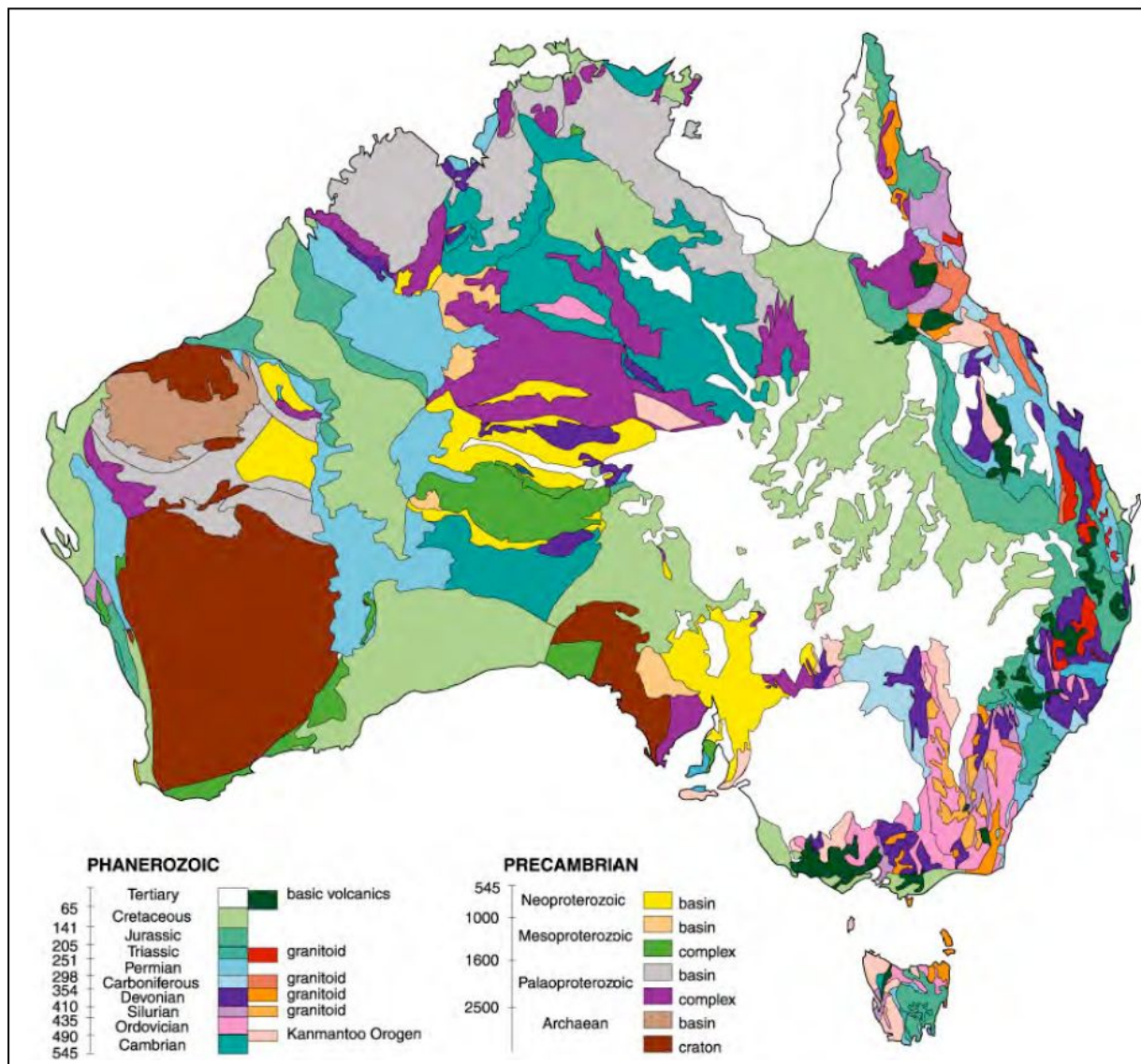


Fig.2, Geoscience Australia, www.ga.gov.au/map

Fig.2 illustrates Australia's geological structure which usually is recorded and listed according to the earth's geological eras. The continent can be divided into several main sections: the Precambrian Archaean cratonic shield (mainly granites), Proterozoic folded strata and sedimentary basins, Palaeozoic fold belts, sedimentary basins and metamorphic rocks from Palaeozoic, Mesozoic and the Tertiary (www.geologynet.com).

The current Australian landmass is composed primarily of Archaean, Proterozoic and some Palaeozoic granites and gneisses. A thin layer of mainly Palaeozoic and Mesozoic sedimentary basins cover much of the continent and are currently undergoing erosion by a combination of aeolian and fluvial processes. One of these basins, the Great Artesian Basin in the north east of the continent, is one of the largest groundwater basins of the world. It was formed between 100 and 250 million years ago and consists of alternating layers of permeable sandstone aquifers and impermeable siltstones and mudstones similar to some of the other sedimentary basins. Here the thickness of this sequence varies from less than 100 metres at the edge of the Basin to over 3000 metres in the deeper parts (www.nlwra.gov.au).

Most famous are the red sandstones of the so-called "red centre", Ayers Rock and the Olgas are outstanding examples. Beneath the sandstone sediments there are only small patches of limestone. Most of the limestone areas were formed during the Cenozoic, which means they are rather young, like the Nullabor Plains limestone and the limestone south of Adelaide (Wopfner, 1997; Ollier, 1988).

Because of its complex geology Australia is very rich on natural resources that are mined in great scale and are one reason for the wealth of the country. Huge coal deposits, bauxite, iron ore, uranium are mined as well as gold, nickel oil and gas and gemstones.

1.4. Soils

In general, the continental pattern of soils is closely related to climatic factors. Mineral or skeletal soils exist over much of arid Australia that contain virtually no organic content and have developed little depth; they may consist merely of a rough mantle of weathered rock. Gypsum is present in many of the desert loams and arid red earths. The soils of the semi-arid regions (where annual precipitation ranges from 200 to 380 mm) are also alkaline, with gypsum or lime a common feature. The organic content of the soils is again low in the solonized (salt-enriched) brown soils and the gray and brown soils of heavy texture that are common in these areas (www.anra.gov.au).

In both the arid and semi-arid regions patterns of swells and depressions caused by the alternate swelling and contraction following wetting and drying of clay soils have developed. They are especially well presented in areas of seasonal rainfall. In areas of 380 to 635 mm of annual precipitation, black earths, brown soils and red-brown earths are the most common soils (www.affa.gov.au).

Superimposed on these climatically determined soil patterns are local variations caused by topography, groundwater conditions, and parent material. In addition, laterite and silcrete originated in remote geological times when conditions were markedly different from those of today. Laterite is represented in every state, including Tasmania, though it is forming nowhere in Australia at the present time, while silicified material is restricted to arid Australia and parts of sub-humid Western Australia, South Australia and Queensland. The term is usually applied to surface or near-surface deposits cemented by silica and is often associated with the formation of mesas and other prominent landforms. Most Australian silcretes are thought to have originated in the middle to late Tertiary era (www.brs.gov.au).

The agricultural landscapes of Australia are supported by a wide range of soil types. Most, but not all, are ancient, strongly weathered, shallow and low in nutrients. This variety, along with the natural limitations of many soils and their interactions with climate, have made it more challenging to develop sustainable systems for agriculture. The fragile nature of the soils makes the land more susceptible to wind and water erosion and degradation from poor land management practices (www.environment.gov.au).

1.4.1. Soils with Limitations

Limitations to productivity have also been induced through human impacts on soils. They have been subject to extensive degradation due to such practices as overgrazing, over cultivation, tree clearing and irrigation. A continuous cover of vegetation on the soil results in the most stable situation. However this is not possible for today's land uses, particularly those in the agricultural sector. While some forms of degradation such as nutrient deficiencies can be corrected, others, such as soil erosion, compaction, acidification and salinisation are difficult to remedy.

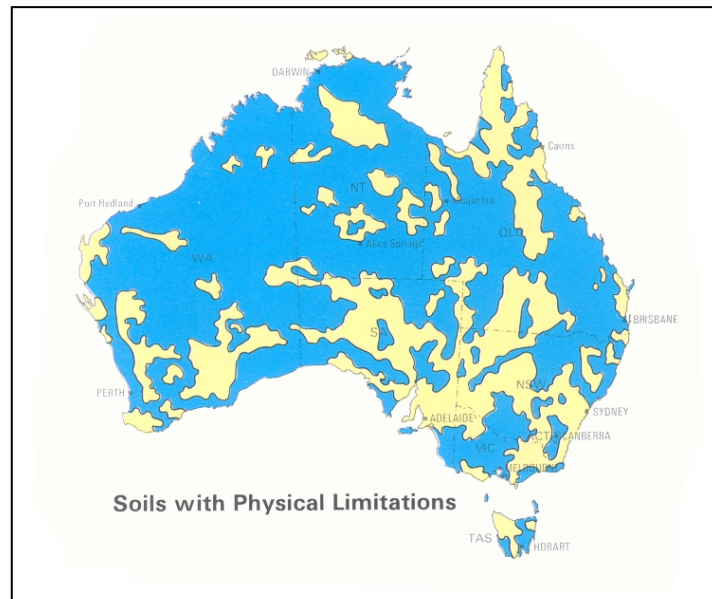


Fig.3, Soils with limitations, Bureau of Rural Sciences Australia

As shown clearly on the map Fig.3, soils with some kind of physical limitations for plant growth and agriculture cover most of the continent.

Australia has a high incidence of acidic soils (ph less than 4.8), usually where rainfall is high. Soil-acidity is a particular problem in many of Australia's low-lying coastal regions, especially in areas where mangrove swamps have been cleared (Queensland). Coastal acid sulfate soils can manufacture large quantities of sulfuric acid, which reduces water quality in rivers and estuaries, killing fauna and flora. Protecting coastal areas and fragile wetlands is of foremost importance (www.csiro.au).

Salt affected soils, sodic and saline, cover more than two thirds of Australia. Soil salinity occurs when extremely high levels of salts accumulate within the soil. Sodic soils contain lower levels of free salt than saline soils, but the sodium attached to clay particles in the soil causes soil structure to break down, leading to erosion and waterlogging so that in some instances, farmed land even has to be abandoned (www.asris.csiro.au).

Some soils of the northern hemisphere have no equivalent in Australian terminology like the term loess which is widely avoided in the Australian context (University of Adelaide, 2007). Being a periglacial late Pleistocene sediment it is negligible on the Australian mainland. In general, comparing Australian soils with soils in the Northern Hemisphere, Australian soils have less organic matter and poorer structure and tend to be quite clayey (except in the west of the continent where they tend to be more sandy).

1.4.2. Soil Orders According to Soil Atlas of Australia

Subsurface layers with a sharp increase in clay content are widespread (*Kurosol*, *Chromosol* and *Sodosol* soil orders) and can restrict drainage and impede root growth. Soils with periodic subsurface or surface waterlogging are some of the clay characteristics that cause problems for engineering and farming because of their ‘shrink and swell’ nature. Soils affected by salt, either now or in geological times, cover large portions of the arable land of the continent (*Sodosols*) and they have various nutrient and physical limitations. Cracking clays (*Vertosols*) cover a very large area in the eastern part of the continent, *Rudosols* and *Tenosols* are widespread on the large red and yellow sand plains in the arid zone. *Kandosols* in northern and eastern Australia are deep weathered soils with low level of nutrients. *Calcerosols* contain calcium carbonate, can be hard-setting soils with high proportions of salinity, alkalinity and sodicity, Fig.4 (www.sciencedirect.com; Isbell, 1996).

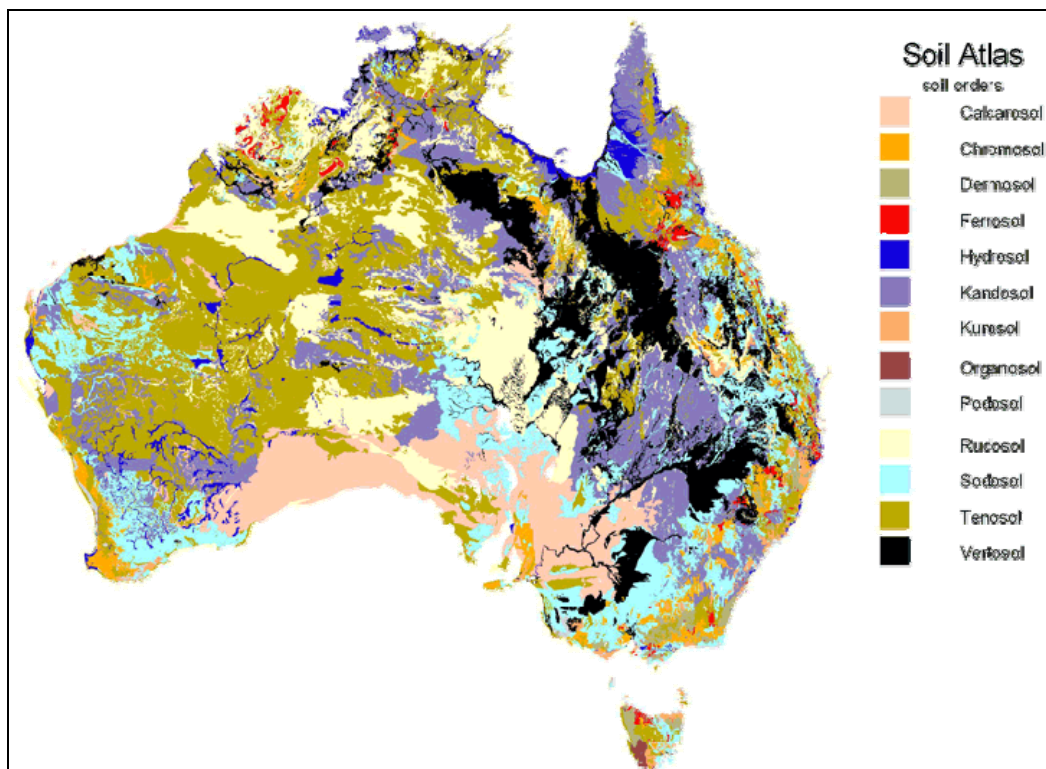


Fig.4, Australian Surveying and Land Information, 2004

Fig.4 shows the soils of Australia classified using the Australian Soil Classifications, the current national standard (www.clw.csiro.au/aclep; Isbell, 1996).

Australia's rate of soil formation is low by world standards, taking over thousand years in many parts of the country to form 3cm of soil. Dust storms can cause large losses of soil, for example the 1983 Melbourne dust storms resulted in a loss of more than 2 million tonnes of soil! (Fig.5)



Fig.5, www.abs.gov.au

1.4.3. Characteristic Soils of Southwest Australia

The map on the following page (Fig.6) shows the distribution of the characteristic soils in the southwest of Western Australia. Salinity attacks most of these soils and constitutes a major problem which is increasing by the year (see following chapters) (Schoknecht, 2004).

The main Soil Categories

Soils with shallow water tables that are wet in some part of the profile for a major part of the year stretch parallel to the coastline in the west and the south. The gravelly soils are dominated by ironstone gravel and cover mainly the Darling Ranges and foothills (Chromosols and Tenosols). The deep sandy (to at least 80 cm) and sandy earth soils cover the northern part of the southwestern agricultural district (Calcarosols). These soils are sandy at the surface and sandy to loamy at depth. The loamy earth soils with a loamy surface and clayey depth build the northern rim of the district. The duplex soils with a texture contrast within the top 80 cm (e.g. sand over clay, loam over clay) are distributed throughout the biggest inland part of the agricultural southwest (Sodosols) (www.agric.wa.gov.au).

Characteristic Soils of South-Western Australia

(Based on proportional allocation of soil groups to soil-landscape systems, April 2002)

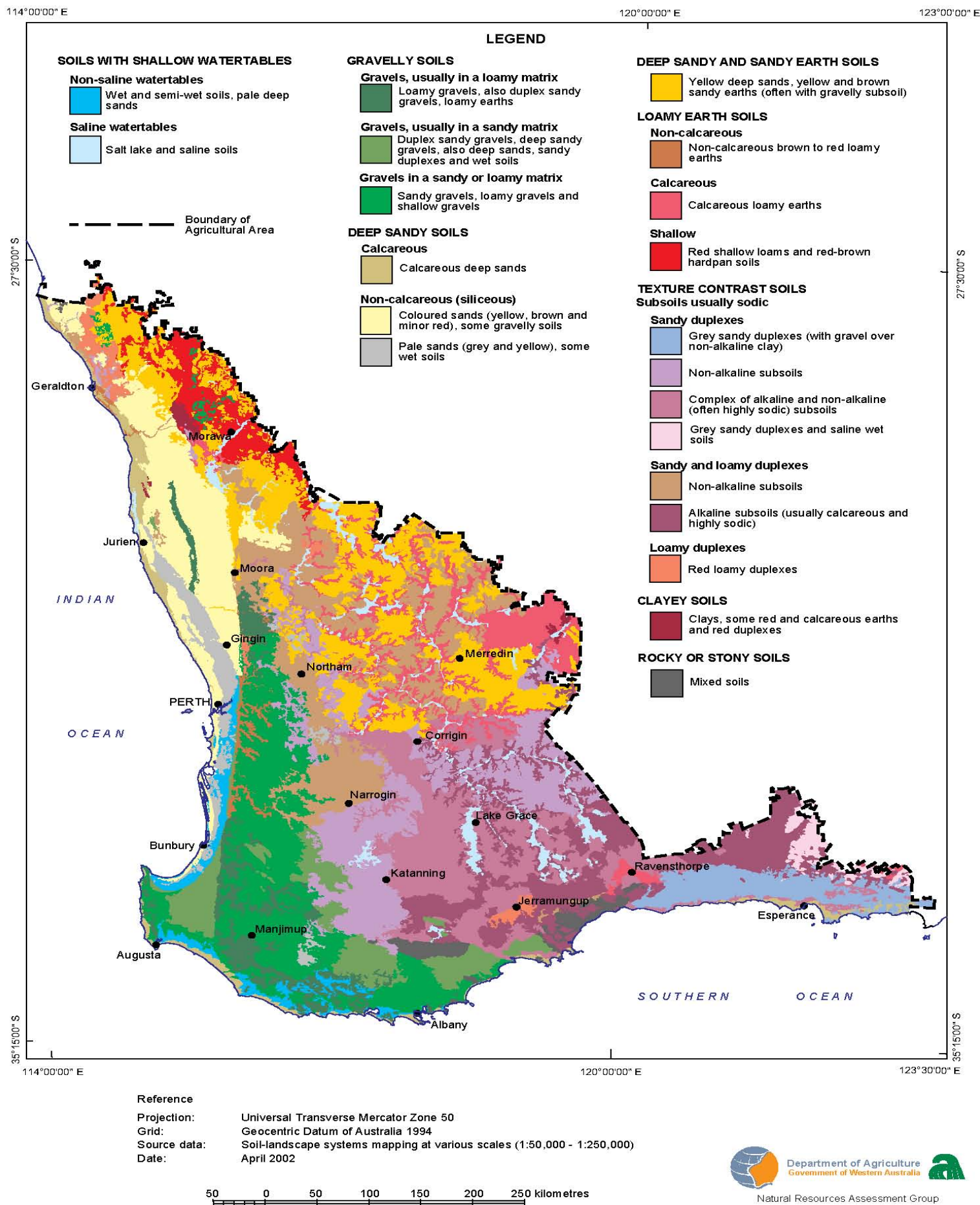


Fig.6, www.agric.wa.gov.au

1.5. Climate

There have been many changes in the climate of Australia in the past, but these were not due to the changing latitude. Even when Australia was close to the South Pole, the climate was warm and wet. This climate persisted for a long time, despite changes in latitude. It was probably under this climate that the deep weathered iron-rich profiles that characterize much of Australia were formed. Aridity only seems to have set in after Australia had reached its present latitude, and the northern part probably was never arid (Jeans, 1986).

The present Australian climate is overwhelmingly arid: one third of the continent is desert and another third is semi-arid. Some sand dunes and stony deserts or gibber plains (covered with small stones or 'gibbers') occupy the major part of the Australian deserts. Salt lakes occur in many low positions, in places following lines of ancient drainage. They are often associated with lunettes, dunes formed on the downwind side of lakes. Many important finds of Aboriginal pre-history have been made in lunettes. Despite the prevalence of arid conditions today, real aridity seems to be geologically young, with no dunes or salt lakes older than a million years (Ollier, 1988).

Outside the polar-regions, Australia is the driest continent. Though its size and latitudinal position allow for a great range of climates, it is generally characterized by a low mean precipitation of about 420 mm, a low mean runoff of 50 mm, and high water losses of about 370 mm. Of primary concern are usually the average or median amounts with the ranges and distribution, in a real and temporal sense. But average values are particularly here in Australia of limited value because high fluctuation rates from year to year make this country one of climatic and hydrologic extremes; that is reflected in the quick succession of drought and flood which can happen within a week. Drought is a common occurrence in Australia, at any time, some part of the country is experiencing drought (www.bom.gov.au/climate).

Australia is located mainly between latitudes 15 and 35 degree south and as such is dominated by the subtropical high pressure cells, passing from west to east. These are normally associated with stable conditions, clear skies and low rainfall. The climates range from the hot seasonally moist north to the more temperate southeast and from the hot dry centre to the wet winters and hot dry summers of the "Mediterranean" southwest.

1.5.1. Australia's Climate Types (Köppen Classification)

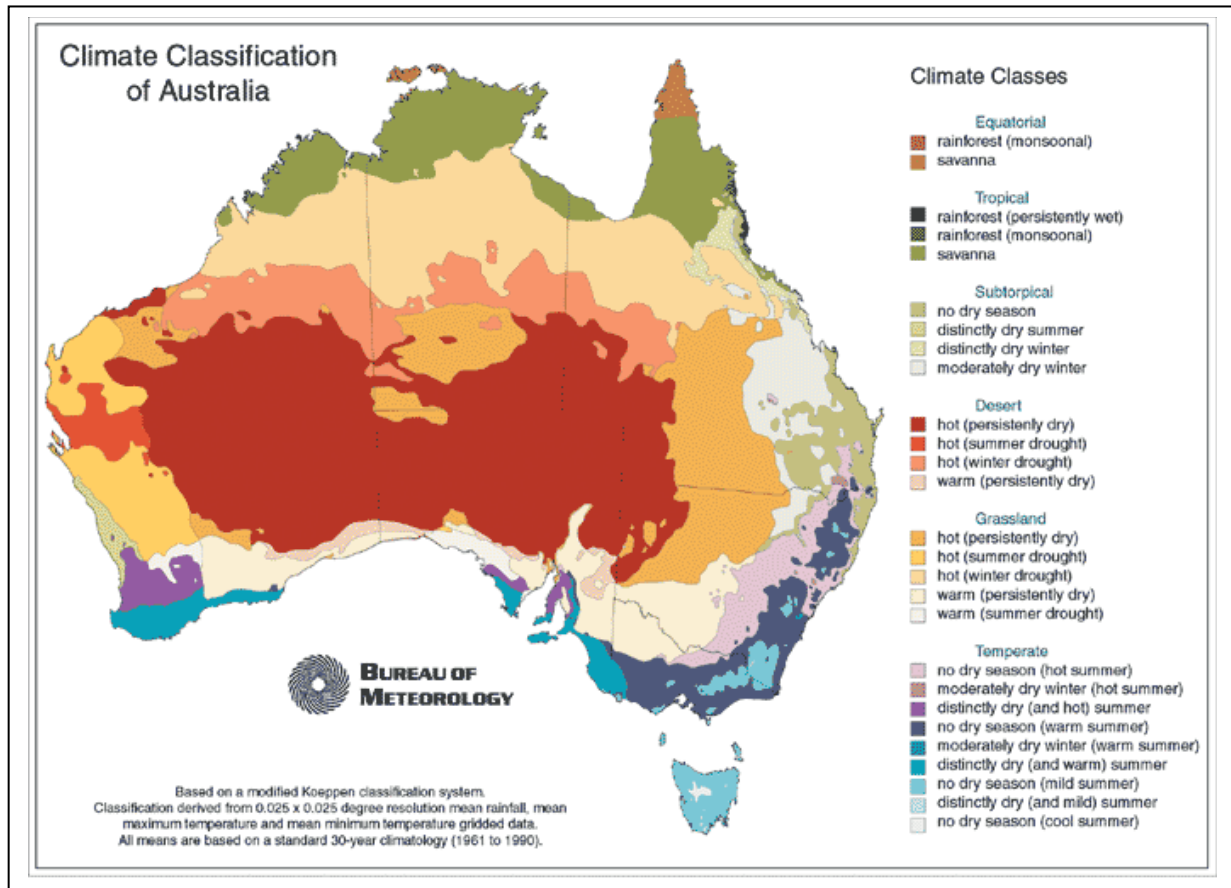


Fig.7, Climate classification of Australia after Koeppen (Australian Bureau of Meteorology)

1.5.1.1. Four main Areal Categories of Rainfall may be defined:

Based on the climate classifications of Fig.7, four combined main rainfall regions can be defined:

1.5.1.1.1. North and East

In the north and east, particularly on the coastal margins, most rain falls in summer. The thermal equator is then over the landmass and a semi permanent low-pressure system develops. Monsoonal rains drawn in from the north are associated with this. Tropical cyclones from both northwest and northeast can supplement falls at irregular intervals over wide areas.

1.5.1.1.2. Southwest

In the southwest, southeast coastal areas and Tasmania, much of the rain falls in winter. During this period, the high-pressure cells are to the north over the mainland and cool polar maritime air is brought in around low-pressure centres and their associated cold fronts. These move from west to east in constant succession.

1.5.1.1.3. Parts of the Southeast

Parts of the southeast are affected by both regimes and therefore get a fairly uniform precipitation. There is no distinct dry season as in the north or south.

1.5.1.1.4. Inland

Inland from this wetter perimeter zones and involving about two thirds of the continent, average rainfall is low enough for the areas to be considered arid or semi-arid (www.bom.gov.au).

While this fourfold pattern is evident in median or average totals, great variations in input can and do occur annually, seasonally and even monthly. An extreme example shows the kind of variation possible in the far northwest. Port Hedland has a median annual rainfall of 273 mm but this has ranged from 32 mm to 1 019 mm (Dept. of National Development 1990). The driest area is Lake Eyre with an annual rainfall of 125 mm, and the wettest is Mount Bellenden Ker in northern Queensland with a median annual rainfall of 4048 mm. In 1979 Bellenden Ker had the highest recorded annual rainfall: 11 251 mm or over 11 metres.

1.5.2. Average annual Rainfall

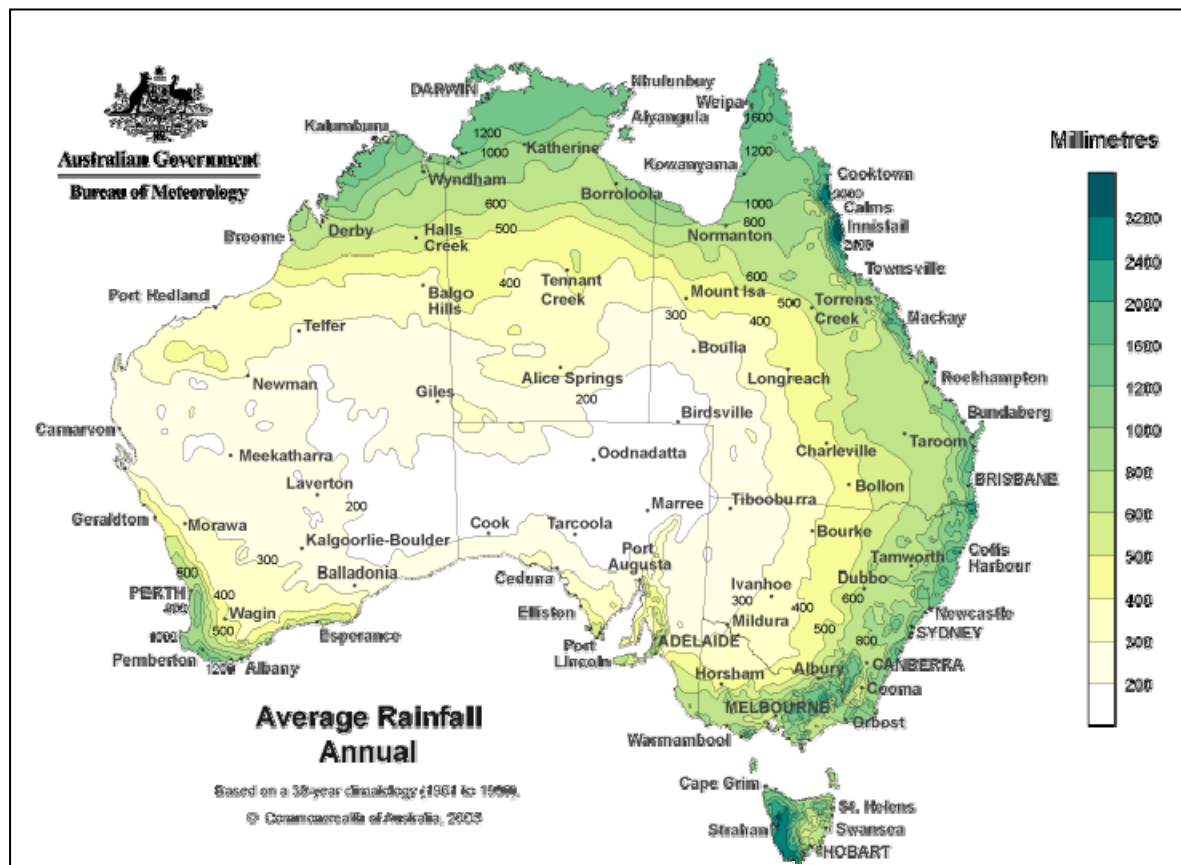


Fig.8, www.bom.gov.au

The average annual rainfall (Fig.8) centres on the extensive arid core of the continent. Around the core is the broken margin of humid lands. In the west, aridity extends to the coast.

From this map it is apparent that most rain falls along a fairly narrow coastal perimeter and even this is discontinuous in the south and northwest. The following indicates just how dry large parts of the continent are:

0,8% of total area – less than 102 mm

51,4% of total area – less than 305 mm

62,5% of total area – less than 406 mm

3,9% of total area – more than 1 194 mm

0,6% of total area – more than 1 600 mm

(Dept. of National Development 1990)

The only areas away from the coast receiving moderate to heavy falls are in the Snowy Mountains and the western plateau of Tasmania.

But the extreme variability of the climate can suddenly bring intense high rainfall that can lead to flooding of streams. Most extreme flooding is associated with influences coming from the tropical and sub-tropical oceans and seas. A tropical cyclone involves the circular movement of air at high speed towards an area of very low pressure. This convergence of air results in torrential downpour. Cyclones, once they have crossed the coast and lose intensity, become rain depressions and cause extensive flooding (Bureau of Meteorology/climatic atlas of Australia).

1.5.3. Average annual Temperature

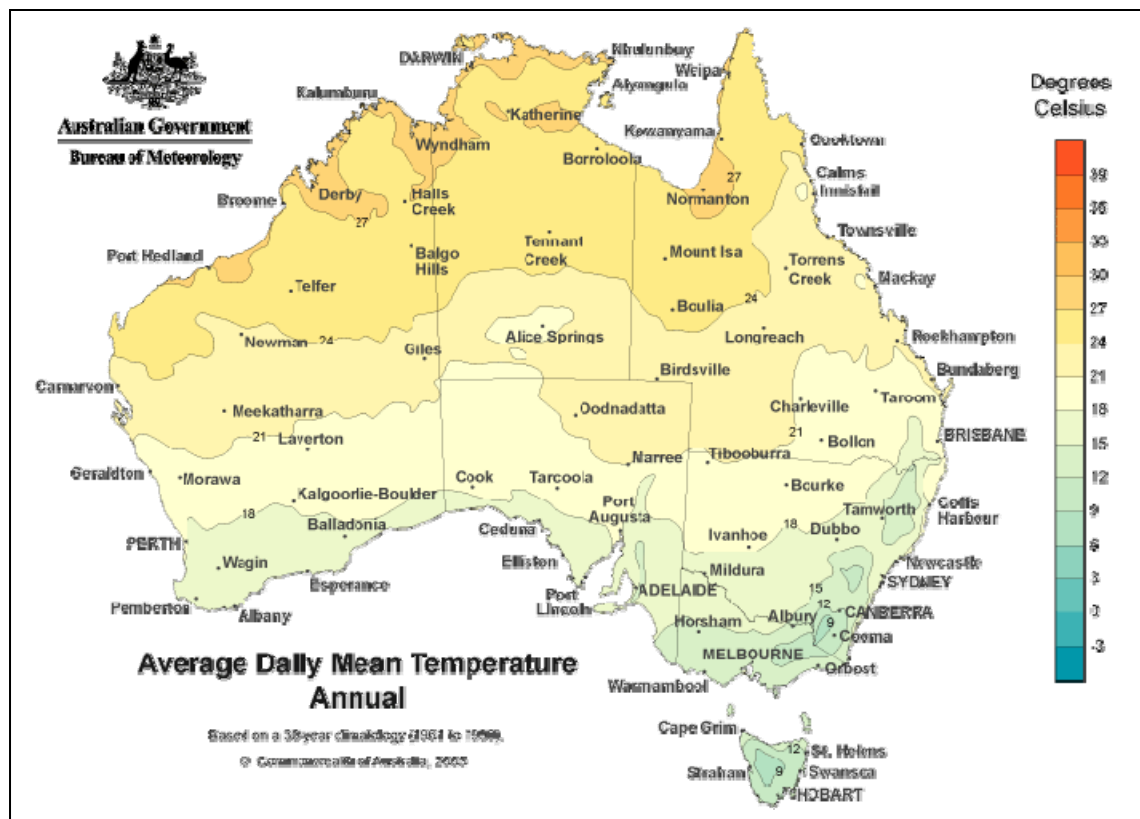


Fig.9, www.bom.gov.au

Fig.9, the average daily mean temperature map, shows that Australia in terms of duration and intensity of heat over large areas is the hottest of the continents. Its situation predominantly under the subtropical subsidence, leading to clear air and great dryness, and its low altitude, make it a unique landmass in the southern hemisphere. The average hottest months are November in the far north, December further south and February along the west coast (due to certain ocean circulation) (Gentilli, 1972).

The high temperatures are the main determinant of high water consumption in Australian cities and in agriculture.

Temperature affects living conditions and plant growth; it directly affects the evaporation of moisture. High humidity and high temperatures create stress for all living beings. The highest recorded temperature was 53 degrees Celsius at Cloncurry in Queensland in 1889. Marble Bar in northern Western Australia recorded the longest hot spell – 160 days over 37.5 degrees C in a year (www.bom.gov.au).

1.5.4. Regional Climate Southwest Australia

1.5.4.1. Rainfall

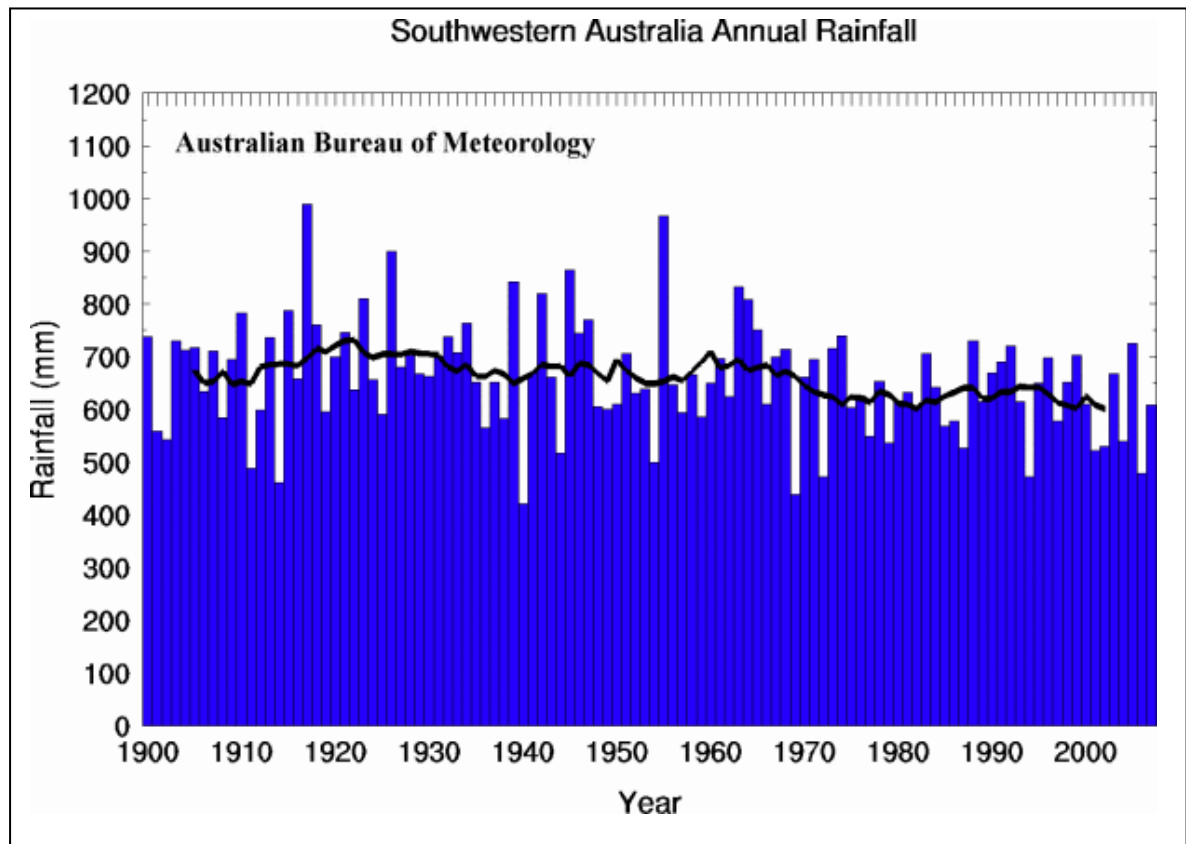


Fig.10, www.bom.gov.au

The southwest of Western Australia which is the part of the country suffering most by salinisation and rising groundwater tables has an average rainfall of about 600 to 700 mm per annum (Fig.10).

The potential annual pan evaporation compensates the precipitation by far. Especially during the summer season (Fig.10) compared to the winter season (Fig.11a) moisture is lost through direct evaporation and transpiration, that can concentrate salts in the upper layer of the soil profile (www.agric.wa.gov.au). Even during the winter months the evaporation is still noticeable (Fig.11b). The hot winds blowing from the east in the summer also play an important role in the evaporation and the removal of moisture.

1.5.4.2. Summer and Winter Evaporation

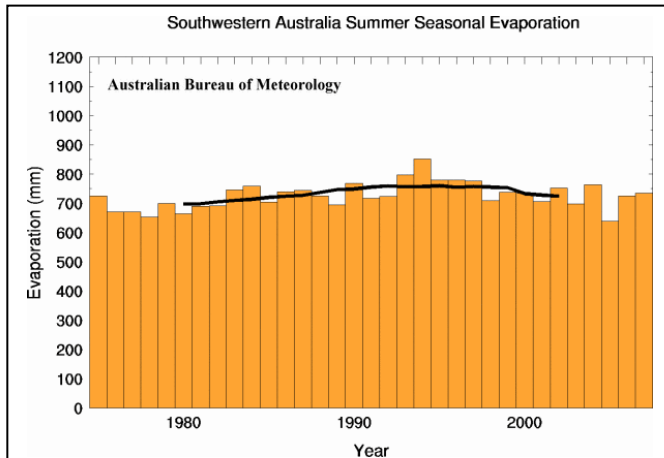


Fig 11a, www.bom.gov.au

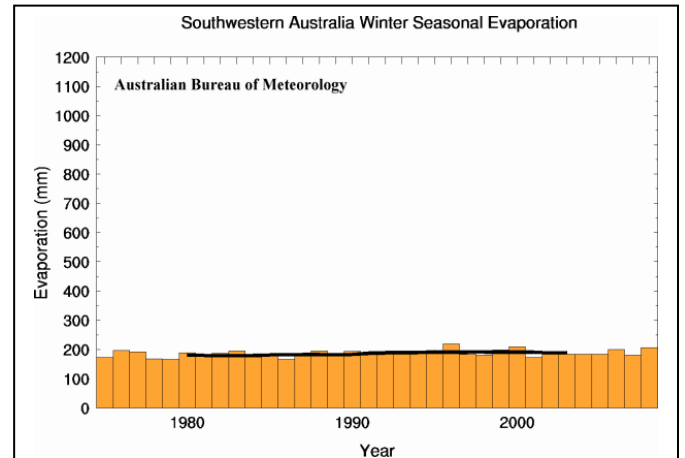


Fig.11b

1.5.5. Summer Wind Roses

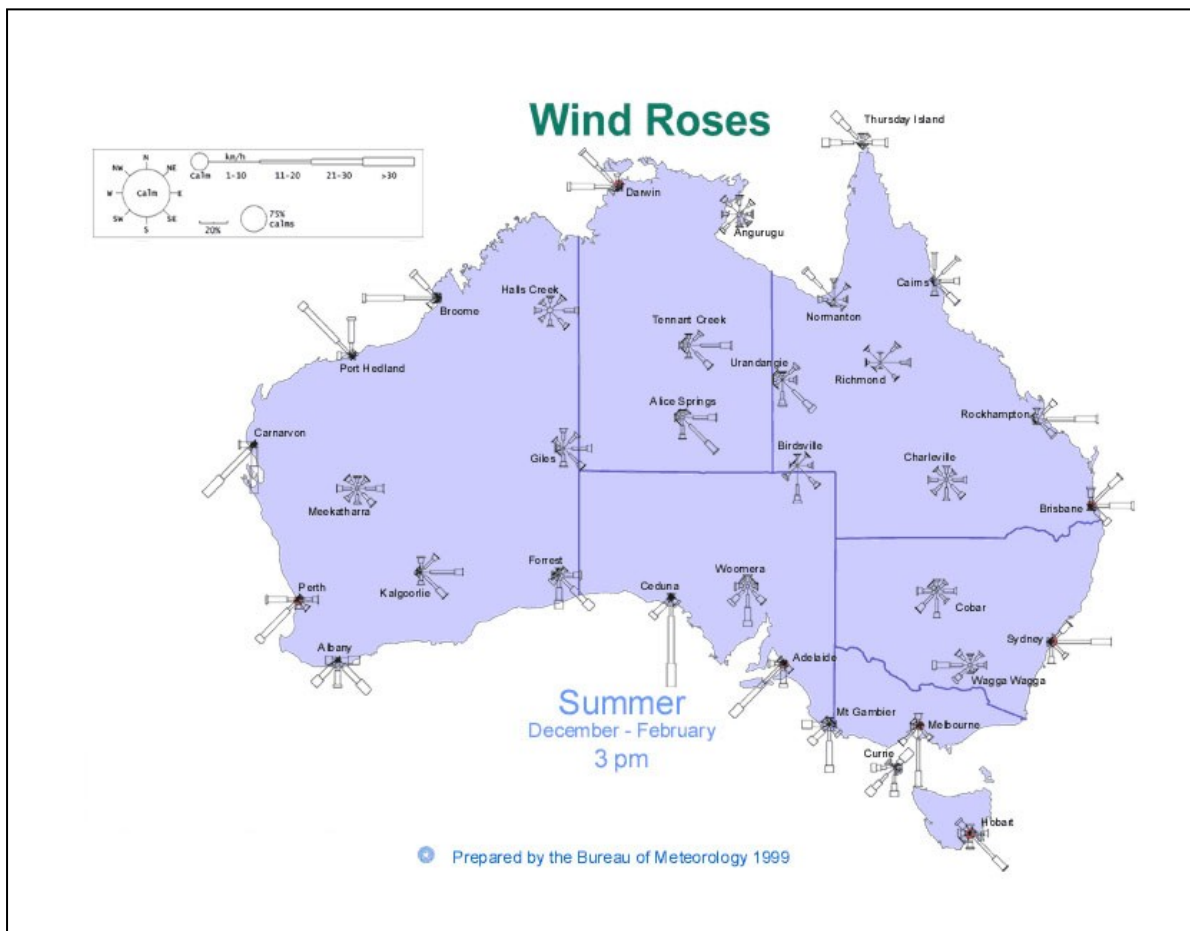


Fig.12, www.bom.gov.au

The wind roses for summer (Fig.12) show that the wind blows mainly towards the centre. In the north there are prevalently monsoonal winds. Over most of Australia the wind varies daily with the transit of the anticyclones. The long arms of the coastal stations show the strong frequency of sea breezes (mainly in afternoons). The tropical easterlies coming from higher latitudes are normally cool but by crossing the centre they normally over-heat as they travel over hot land. They transport heat and dry out the landscape by soaking up moisture, an effect which can be especially noticed in the agricultural area of the southwest of the continent, one of the worst affected areas by salinity.

Wind roses in Australia present wind speed generally in kilometres per hour and are based on at least 15 years of records. The percentage of calm conditions is represented by the size of the centre circle – the bigger the circle, the higher is the frequency of calm conditions. The branches (coming from eight directions) are divided into segments of different thickness which represent wind speed ranges from that direction. Speed ranges of 10 km/h are used. The length of each segment within a branch is proportional to the frequency of winds blowing within the corresponding range of speeds from that direction (www.bom.gov.au).

1.5.6. Average annual Evaporation

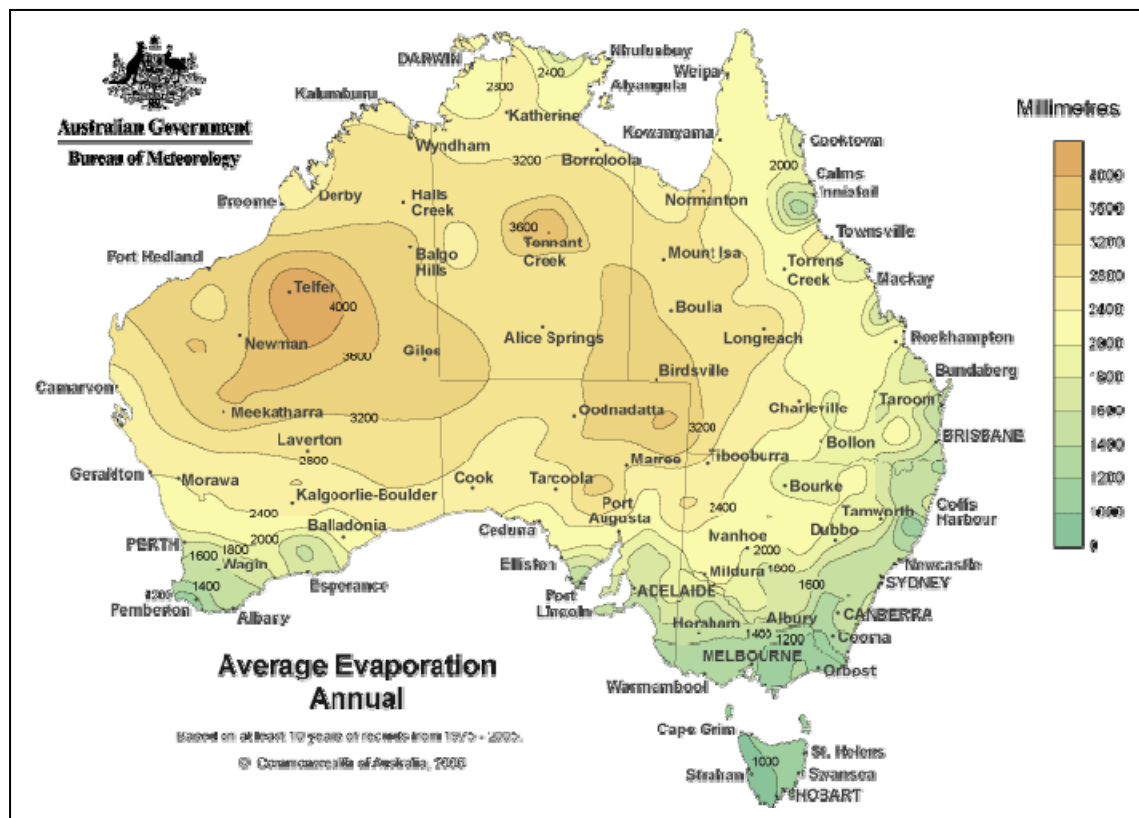


Fig.13, www.bom.gov.au

Australia's precipitation is subject to high rates of evaporation (Fig.13) and transpiration relative to other continents, because of high prevailing temperatures, high levels of radiation, low humidity and generally stable conditions. In the wet areas of the southeastern parts of the country and Queensland in the northeast, there usually is a balance between evapotranspiration and rainfall or an excess of precipitation which then runs off. In dry areas such conditions only prevail after infrequent inputs of rain.

In the north with predominantly summer rain the actual evapotranspiration equals the potential most of the wet season. However in dry winters which are still warm, actual is less than potential evaporation (www.bom.gov.au).

In the southwest and parts of the southeast division, winter rains predominate. Water surpluses occur in the cooler half of the year with almost equal actual and potential evaporation. Although summers here are not as dry as winters in the north, high temperatures and lower rainfall reduce the actual evapotranspiration beyond the potential. Therefore a recognizable deficiency occurs which puts pressure on soil moisture and plants (Jeans, 1986).

1.6. Vegetation

The wide range of climatic types in Australia is reflected in a similarly wide range in the vegetation. This includes tropical rain forests, tropical parkland and grassland, scrub, desert, and temperate grassland and forests.

The distinctive character of the natural vegetation in Australia is related to the distinctive nature of the native flora. Many of the native plants differ markedly from those of any other region. The most prominent and widespread of the essentially Australian elements are the eucalyptus, which require more humid conditions, and the acacias, which are the main species of woody vegetation in arid and semi-arid areas; but there are many other significant groups, including the hummock grasses or 'spinifexes' (www.csiro.au).

After over two centuries of European occupation, the vegetation has been modified in many places. However the native elements continue to give a distinctive Australian character to most of the actual vegetation of the present day. The nature of the plant cover reflects the major environmental factors, and in particular the aridity and infertility that are characteristic of much of the country. The overall pattern of distribution of the vegetation is related to the rate of effective precipitation, and notably to the general decline towards the interior of the continent.

Before European settlement the plant cover of Australia could be regarded as 'original natural' vegetation. Human influence was limited to hunting and gathering activities of the sparse Aboriginal population. And whatever the influence (e.g. use of fire) of Aboriginal man may have been, it surely was minor in comparison with later European disturbances.

At the onset of European settlement, the arid nature of Australia was reflected in the limited extent of its forests and the dominance of woodland, shrubland and grassland (www.anra.gov.au).

1.6.1. Major Vegetation Groups

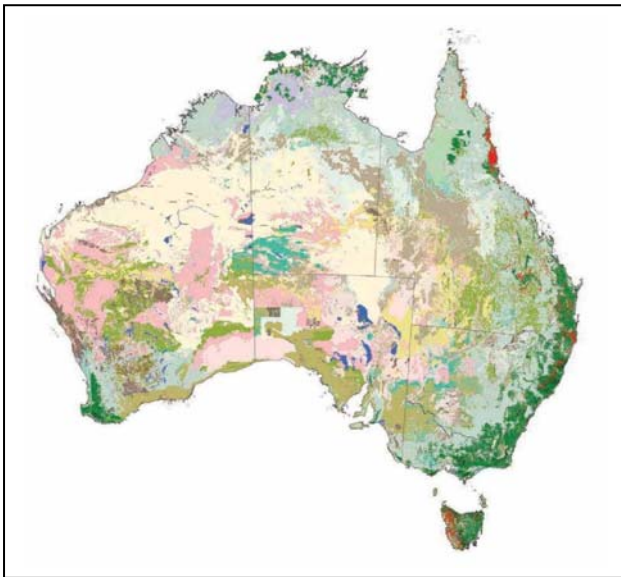


Fig.14a

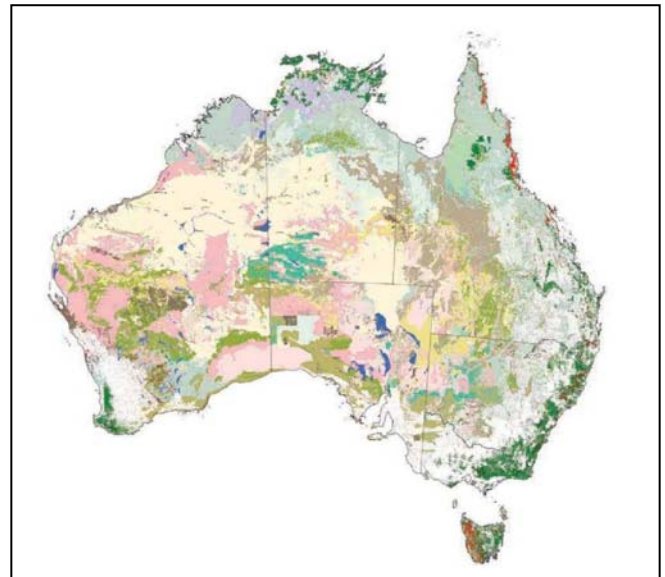


Fig.14b



Dept. of the Environment and Water Resources, 2007

The above maps (Fig.14a and b) present an overview of Australia's Major Vegetation Groups (MGVs) and the estimated impacts they have sustained since European settlement in Australia.

(Fig.14a) points out the estimated pre-1750 distribution of Australia's MGVs showing a likely view of native vegetation on the Australian continent prior to European settlement. The term "pre-1750" is not really corresponding exactly with the year of the onset of European settlement but it is widely used internationally in greenhouse science and vegetation monitoring to describe the time just prior to industrialization.

(Fig.14b) presents a map of the current distribution of MGVs. Comparison between Fig. 14a and Fig.14b shows the impact of changes to the management of Australia's native vegetation since European 'invasion'. It is far from being a 'natural' vegetation.

1.7. Hydrology

In a continent dominated by dryness, water is one of the most valuable natural resources. Growth of demand for urban purposes, agriculture, livestock and irrigation is putting pressure on available resources. The unevenly distributed and unpredictable rainfall, high temperatures and high evaporation make water management even more difficult. Adding to the diversity of climatic regimes are the different infiltration rates over the various basin drainage types (Jeans, 1986).

1.7.1. Surface Water

For data purposes Australia is divided into twelve drainage divisions:

Firstly there is an important and relatively narrow zone of coordinated exterior drainage. This includes: 1, North East Coast (Queensland); 2, South-East Coast (east and south of the Great Divide); 3, Tasmania; 5, South-Australian Gulf; 6, South-West Coast (land draining the area north and south of Perth); 7, Indian Ocean (dry area of north west); 8, Timor Sea (far northwestern Australia, wet summer tropics centred on Darwin); and 9, Gulf of Carpentaria (all lands draining into this gulf). 4, the Murray-Darling division, is a coordinated internal drainage system with an external outlet for part of its total discharge. 10, Lake Eyre, is also an internal drainage system with but only very low inputs being removed by high evaporation. The final two divisions, 11, Bulloo-Bancannia, and 12, the western Plateau system, have also no drainage into the ocean (Department of Minerals and Energy, 1980).

Only the external divisions have on average a positive water balance, with an excess run off ranging from 12 mm for the Indian Ocean to 690 mm for the Tasmanian division.

1.7.1.1. Annual Yield

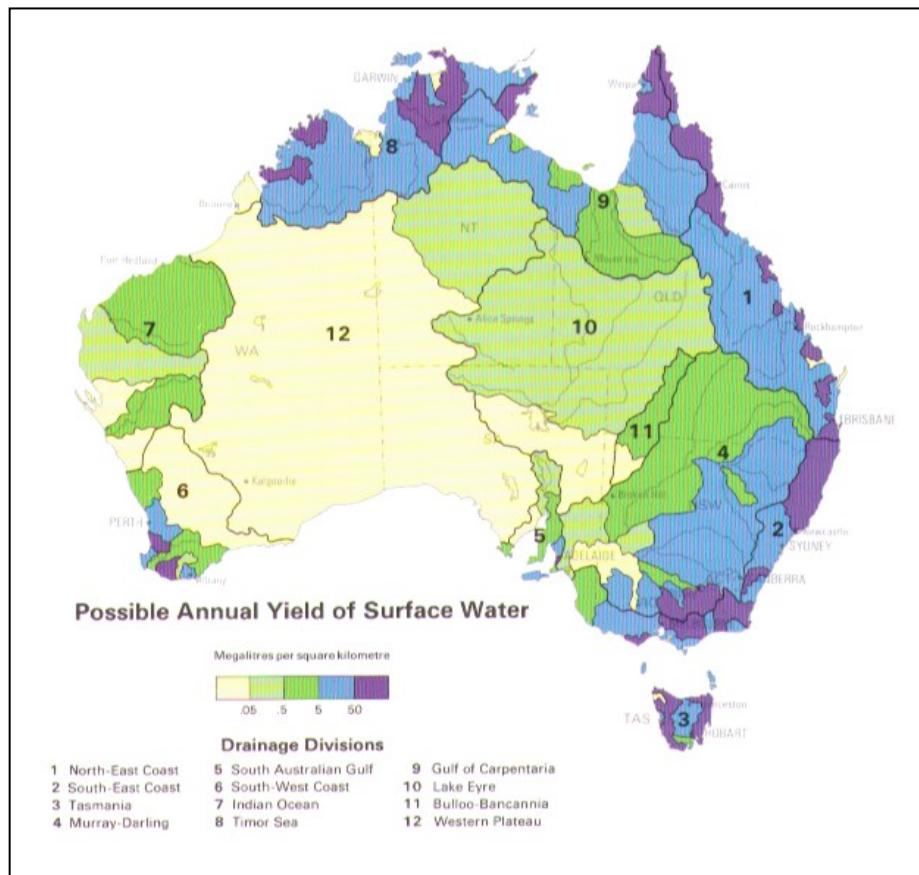


Fig.15, Australian Surveying and Land Information, 2004

Fig.15 gives a detailed account of the different drainage systems with the respective possible annual surface water yield.

Fig.16 below shows the actual annual surface water yield of those divisions.

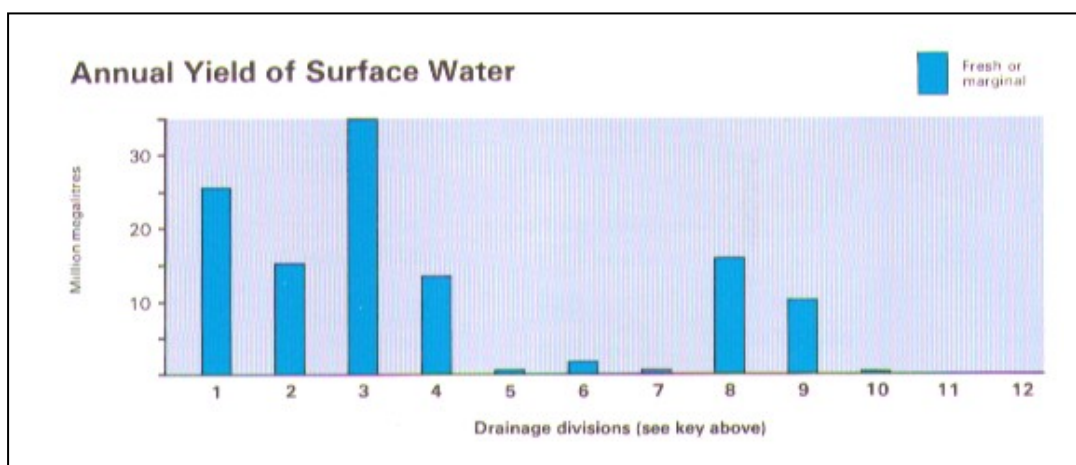


Fig.16, Australian Surveying and Land Information, 2004

On the east coast (division 1 and 2) and especially in Tasmania (3) most rivers are short but are a relatively reliable source of water (Fig.15). In Tasmania this high precipitation and the flow of rivers is used for hydroelectric power stations. In the eastern half of the continent, inland streams drain extensive catchment areas. Lack of run-off and loss through evaporation and use means flow declines through most of their courses. Water of the Murray-Darling system (4) are intensively developed for irrigation purposes. The rivers in the north (8, 9) have a large annual volume of flow with seasonal extremes. They flood in the summer and are reduced to a trickle in spring and winter (Australian Surveying and Land Information, 2004).

1.7.1.2. Annual Run-off

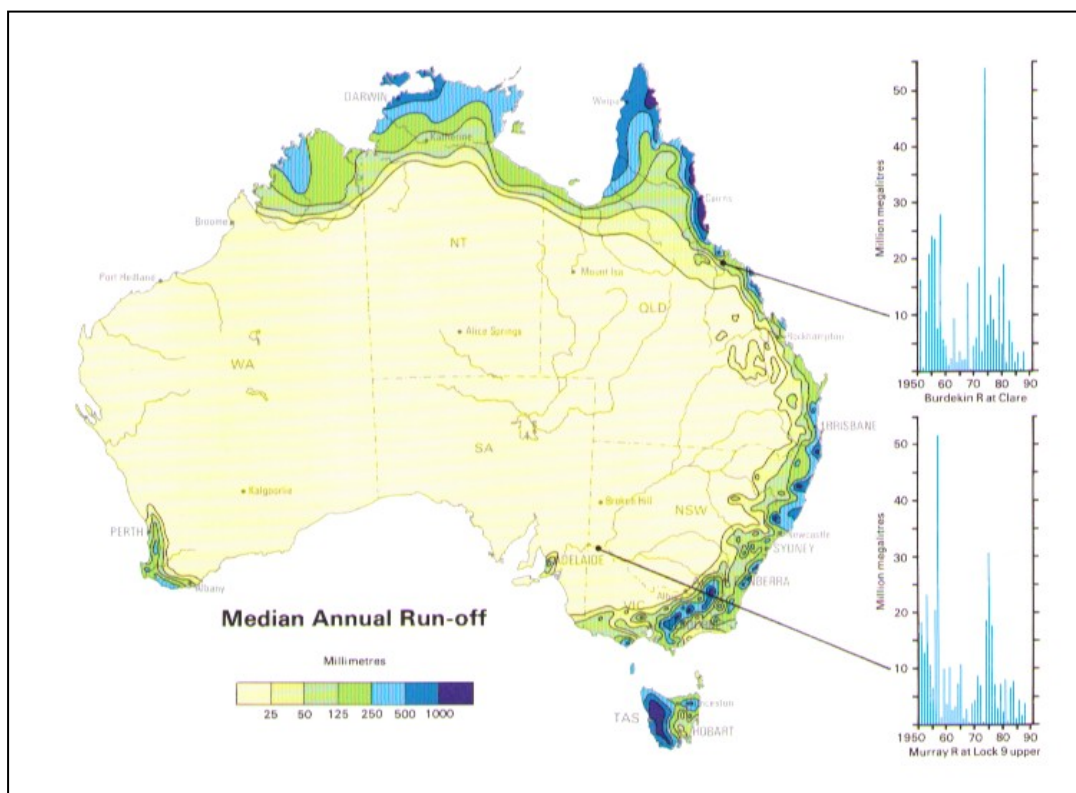


Fig.17, www.bom.gov.au

As seen in Fig.17, areas with a significant run-off into the rivers from precipitation are very limited. The variability of rainfall is reflected in the annual flow of the biggest Australian river, the Murray, in the southeast and the Burdekin in Queensland's north.

From Fig.15, Fig.16 and Fig.17 it can clearly be seen that the actual and possible yield of surface water and run-off vary in most parts of the continent. Only in the coastal areas they keep some balance. In the drier regions, to secure water supply, many schemes have been developed to store water for irrigation and other uses. Along rivers, local pumping stations provide irrigation. Major streams are dammed to form major reservoirs. Water storage

reservoirs, where precipitation run-off is collected, supply drinking water for urban areas (Australian Water Resource Council 1992).

Since Australia is a dry continent with a long and varied coastline and a complex geomorphic history, and with a diversity of climatic regimes, numerous basin drainage types exist. Adding to this diversity is high infiltration over sandy terrains, vast sedimentary basins acting as groundwater reservoirs and flanked by ancient shields or denuded mountain ranges which often run close to the coast as divides. Over all this variety are the common factors of low, erratic and infrequent precipitation, high temperatures and consequently high evaporation from water bodies (National Land and Water Resources Audit, 2001).

1.7.2. Groundwater

Water found underground in arid and semi-arid areas partly compensate for the lack of surface water but the salts they usually contain limit their value. Unfortunately use has exceeded rates of recharge. Where some bores were once artesian (flowing under pressure) they now need pumping. Groundwater supplies are important when rainfall is less than 750mm; this includes about 80% of the country. It is or was derived mainly from rainwater, which seeps into great depths in suitable lithologies, where hydrostatic conditions influence its movement. Because movement is very slow, particularly in confined artesian waters, water yields probably fell as rain in much earlier geological times (www.ewatercrc.com.au).

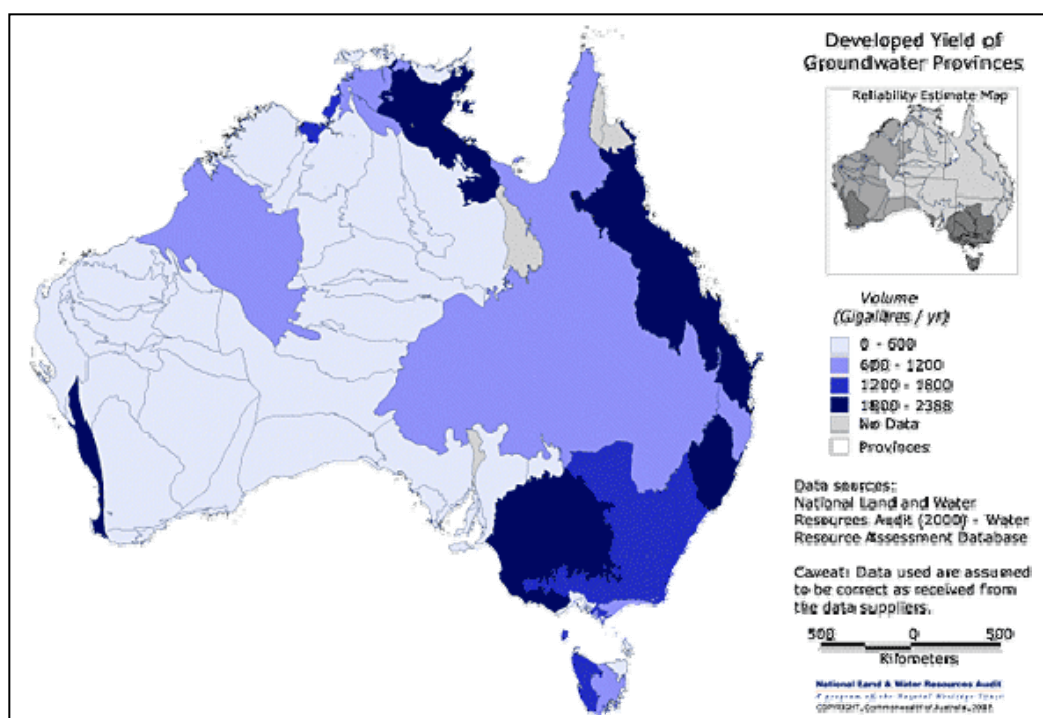


Fig.18, National Land and Water Resource Audit, 2000

Where groundwater supplies intersect the surface as in some rivers, springs, and temporary or permanent lakes, it is subject to evaporation. In this way the internal dynamic balance is maintained in the large and small internal basins which occupy so much of interior Australia.

Fig.19 illustrates the groundwater yield from the main sedimentary basins and drainage divisions. The largest one, covering almost one third of the continent, represents the Great Artesian Basin. To the south lies the Murray Basin and to the east the Drummond/Bowen Basin (www.nlwra.gov.au).

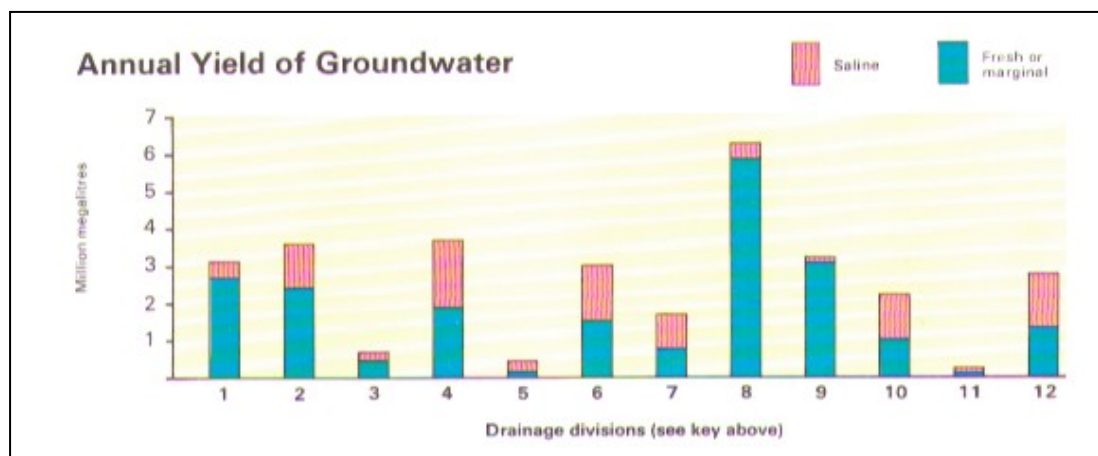


Fig.19, Australian Surveying and Land Information, 2004

This groundwater yield chart (Fig.19) refers to the same regions as shown on the surface water yield map. Surface water drainage divisions almost overlap the underground sedimentary basins.

The map (Fig.20) on the following page gives an overview of groundwater depths in the southwest of the country, an area of rapid increase in salinity. The average depth of the water table lies between 2 and 10 metres, only in the forest covered regions and in the higher ridges the groundwater table remains deeper than 10 metres. The majority of this agricultural area in the southwest has groundwater of moderate to saline quality. The most saline water is found in the northern wheatbelt and in the centre of the southwest agricultural district. The current status of salinity has been based on areas mapped as wet and waterlogged, meaning the profile is saturated for longer than six months; but this does not necessarily imply that the site is saline. However, due to high levels of salt stored in soil profiles, it is highly likely that if these are not presently saline, they are at risk of becoming so (Short and McConnell, 2000).

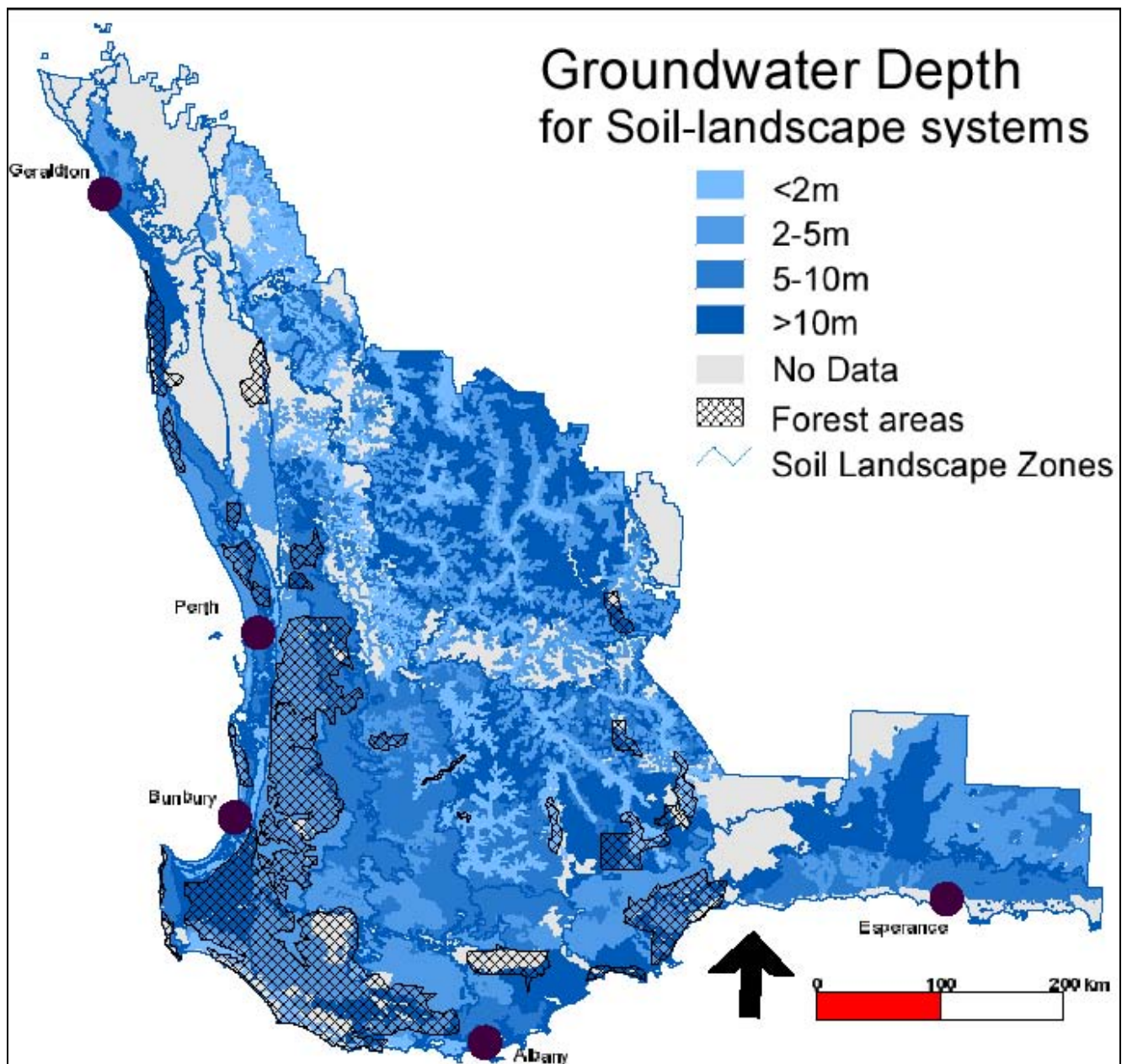


Fig.20, Short and McConnell, 2000

2. Anthropogenic Influences and Impacts on the Environment

At the onset of European settlement in 1788 the arid nature of the Australian continent was reflected in the limited extent of its forests (mainly along the coasts) and the dominance of woodland, shrubland (bush) and grassland. Eucalypts and acacias prevail in the native vegetation. Eucalypts require more humid conditions; acacias are the main species of woody vegetation in arid and semi-arid areas.

Today, the signs of human occupation and cultivation, clearing, pasture improvement and grazing patterns stand out clearly in the vegetation. Even though the original inhabitants, the Aborigines, did also alter the balance of the environment by their practice of burning the undergrowth and setting bushland on fire, their impact was limited compared with the changes caused by European settlement (www.abs.gov.au).

From the 1860s, clearing of forests and woodlands was pursued extensively. The whole appearance of the landscape changed, the balance was disturbed, soil erosion one of the results. The areas most changed are the cultivated lands and the intensively grazed lands in the vicinity of the big urban sprawls. But even in areas where there has been no European settlement, the impact of grazing feral animals (former domestic animals which escaped or where driven away) is evident – mainly by goats, pigs, horses, donkeys, camels, rabbits, and buffaloes in the north (www.worldwildlife.org).



2.1. Population

In 2000 the world's population was around 6 billion with Australia's population representing around 0.3% of this total (World Resources Institute, 2000; www.wri.org).

2.1.1. Population Size and Growth

The estimated current resident population of Australia in 2008 is on 21.18 million. There is no accurate measure of population in 1788; a recent estimate of the Indigenous population then was 750 000, but other estimates have ranged from 300 000 to 1 million. The Indigenous population today is estimated to be 400 000 (ABS, 2008).

Australia's Population growth 1900 to 2000

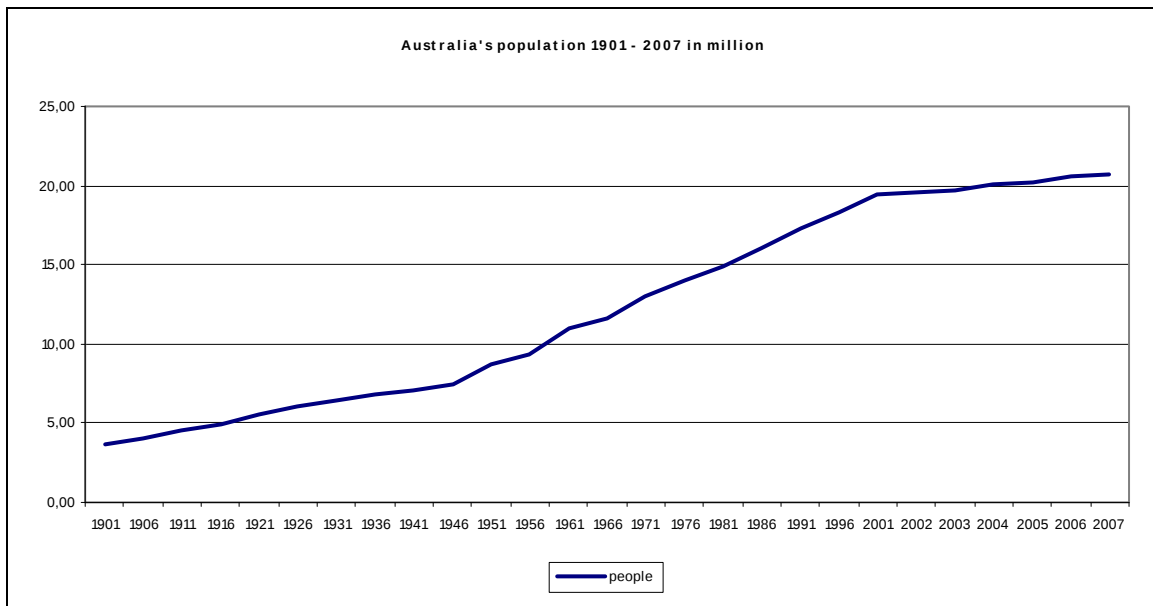


Fig.21, own illustration based on ABS, 2008

The graph, Fig.21, shows Australia's population between 1900 and 2000. Natural increase has been the main source of Australian population growth over the past century. Only for short periods around 1911-12, after each of the two World Wars and again in 1987-89 did net migration exceed natural increase. The rates of growth have been

variable, but the rise between the population in 1900, of around 3.8 million, and 2007 represents an annual growth rate of about 1.7% (ABS, 2008).

2.1.2. Population Projection

The ABS has published population projections for Australia to the year 2101. The population is projected to grow to between 24.1 million and 28.2 million by the year 2051 and to reach up to 31.9 million by 2101. There also will be a shift to an older population by 2051, with a rather big increase in population aged 65 and over. Changes related to an aging population, such as increased consumption in leisure activities, less intensive use of housing in some areas, increased social expenditure by the public sector and high concentrations of older people living in coastal retirement towns, may have direct or indirect environmental effects (ABS, 2001).

Australia's agricultural production at the end of the 20th and beginning of 21st century was enough to provide food for around 55 million people. The projections of the future population suggest that some of the agricultural production currently exported may be needed for domestic use in the future, assuming that levels of agricultural production remain largely unchanged. This will put even more pressure on the natural resources, furthering the debate about how large a population Australia's environment can support. The main arguments are: the limited amount of land suitable for agriculture; the climate patterns and in particular the limited amount of rainfall; the severe nature and extent of Australia's current environmental problems (salinisation!!) (ABS, 2001).

Increasing awareness of the need to protect our environment has up to a point changed the environmental policy in Australia. Key areas of environmental management include: the impacts of land use and in particular, agriculture; the sustainable use of natural resources and materials; minimizing waste and pollution; protecting and conserving biodiversity and ecosystem health (where it is still possible).

There are divergent views on the validity of these arguments and the debate concerning population policy in Australia is ongoing.

2.2. Impacts on Vegetation Cover

Australia's present vegetation has either been established by European settlement through urban and agricultural usage or is a result of grazing animal population. It is far from being a 'natural' vegetation.

2.2.1. Vegetation 1788

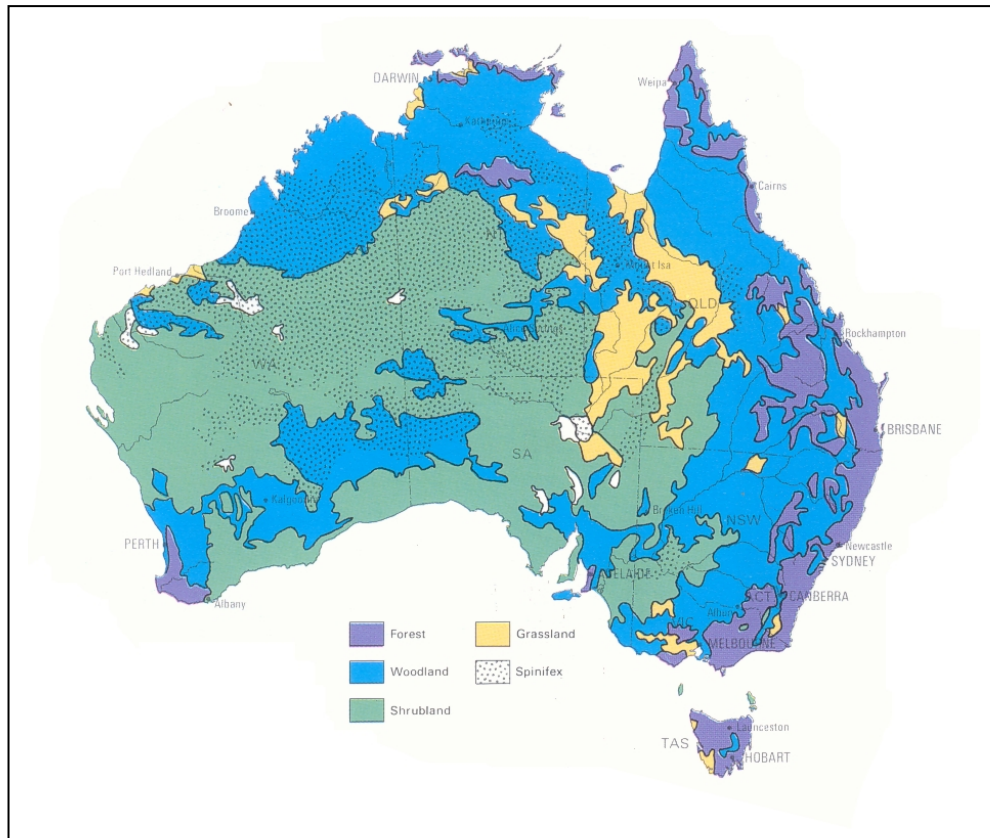


Fig.22, Australia's Vegetation in 1788, Australian Surveying and Land Information, 2004

Fig.22 shows the almost untouched vegetation cover of the Australian continent in 1788 just before European invasion. Woodland and shrubland dominated the arid continent with extensive forests stretching along the east coast.

2.2.2. Present Vegetation

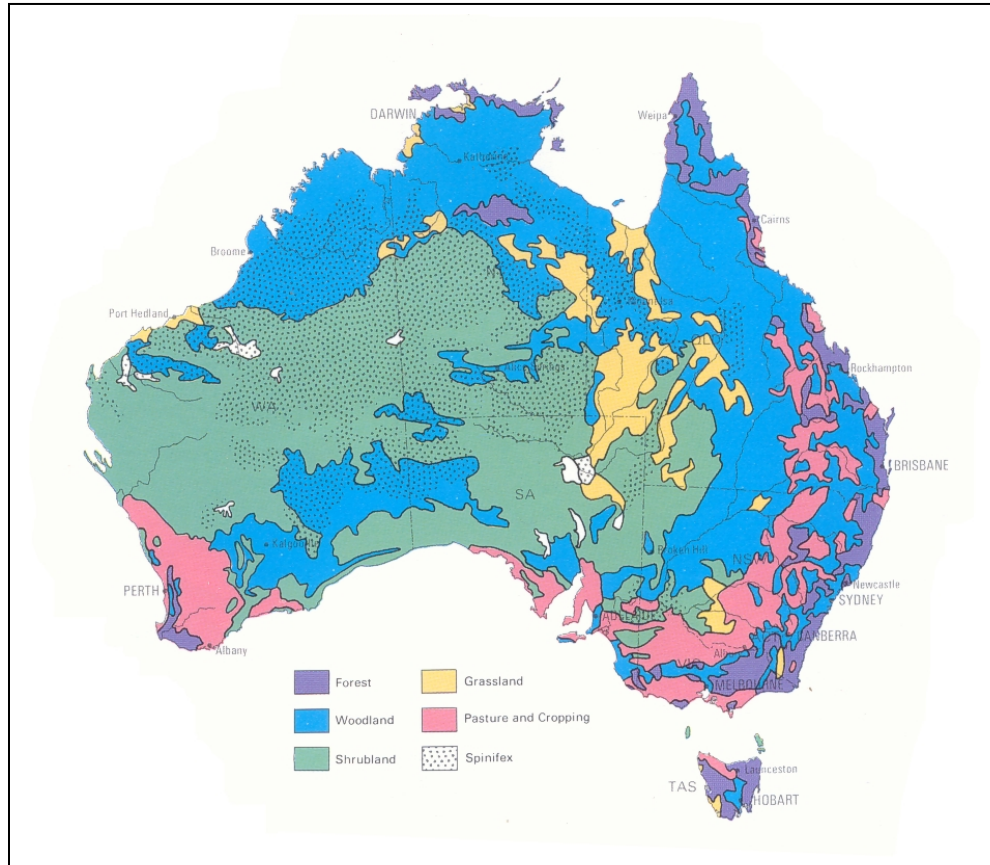


Fig.23, Australia's present Vegetation, Australian Surveying and Land Information, 2004

Fig.23 defines the present vegetation (2001), which has been modified either by European settlement or left for grazing by farm animals. From the 1860s, clearing of forests and woodlands was extensively pursued for the establishment of pastures and agricultural crops. The whole appearance of the landscape changed and disturbed the natural balance. Even in areas where there has been no European settlement, the impact of feral animal grazing is evident (Australian Surveying and Land Information, 2004).

Most of the remnants of the closed forests are distributed in small patches. They are associated with mean annual rainfalls that range from about 1200 mm to more than 2400 mm, and that vary in seasonal variability. These forests belong mainly to the category of rainforests. The canopy height of these trees often exceeds 30 m. They occur at all

latitudes in eastern Australia, from Cape York to Tasmania, and at all altitudes, from sea level to 1200 m and more.

The tropical rainforests occupy only a very narrow belt on parts of the north coast of Queensland. They consist chiefly of evergreens and are similar to the tree-jungles of Southeast Asia. On the coast itself there are mangrove swamps and coconut palms, while the coast of Queensland supports the strange breadfruit tree (www.anra.gov.au).

Further south we find the subtropical rainforest, the warm temperate rainforest and in Tasmania the cool temperate rainforest.

As conditions become less favourable (seasonal droughts, increasing altitude) there is an overall tendency towards types that are of lower stature and generally more resistant.

Farther inland the forests contain species, and even genera, which are exclusively Australian. These include the Queensland *kauri pine* and various Australian species of *Araucaria*, such as the *hoop* and *bunya-bunya pines* (Jeans, 1986).

The greater part of tropical Australia is open grassland with patches of forest, similar to the savannas of Africa. This region extends from about 10 degree south to 20 degree south, where the rainfall becomes insufficient to support more than short grass. In Queensland it provides good cattle country.

Further south, towards the centre of the continent, the semi-desert supports a scrub known as *mallee* (*Eucalyptus*). This changes further inland to a scrub steppe, known as *mulga* (*Acacia*) with patches of *saltbush* (*Kochia*). Much of the *mallee* scrub has become wheat-land.

The deserts that extend across central Australia from the western seaboard to the Great Dividing Range in the east, and south to the Great Australian Bight, support patches of *porcupine grass* (*Triodia*) and a spiny grass called *spinifex*. Only in a comparatively small area in the centre of the continent is there nothing but bare sand. To the east of the deserts, where the rainfall is sufficient for dry pasture, are the Darling Downs, which support an enormous sheep population (www.csiro.au).

The temperate forests are confined to the southwest, the east and the southeast. They contain vast stands of *Eucalyptus* or gum trees; there are more than 600 species. They range from dwarf forms to large trees that may exceed 80 m in height (www.anra.gov.au)

Some of the original areas of forest have been preserved as managed forests, reserves or national parks. However, large areas have been cleared and handed over to cropping, or to intensive animal production sown with exotic pastures. Thus Australia's native vegetation is dwindling fast. In many regions less than 20% of native plant cover remains. The more the native vegetation is divided or fragmented, the less it is able to provide habitat for wildlife or carry out processes like nutrient and water cycling.

Overgrazing also puts stress on remaining trees, so diseases can attack easier. Dryland salinity, caused mainly by excessive clearing of native vegetation, can also destroy large areas of remaining vegetation, as well as making land unsuitable for agriculture (www.agric.uwa.edu.au).

2.2.3. Percentage of Vegetation Loss

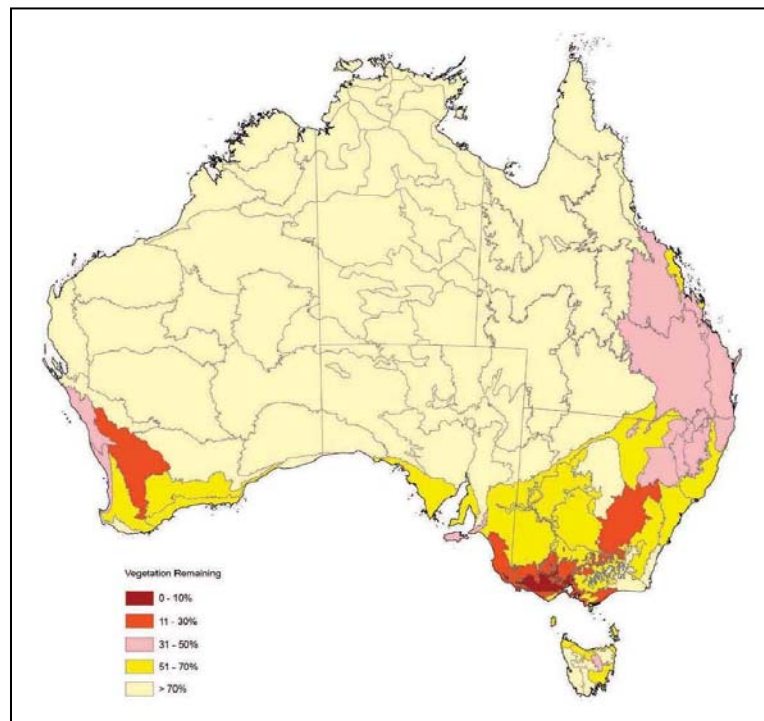


Fig.24, Remaining Vegetation, IBRA, 2005 (www.environment.gov.au)

Fig.24 lays out the degree of loss of native vegetation since European settlement in different areas of Australia, using the interim Bio-geographic Regionalization of Australia (IBRA; it divides the continent into 85 bio-regions with 403 sub-regions) as a reporting unit. The correlation between native vegetation loss and intensification of agricultural land use is clearly visible in this illustration.

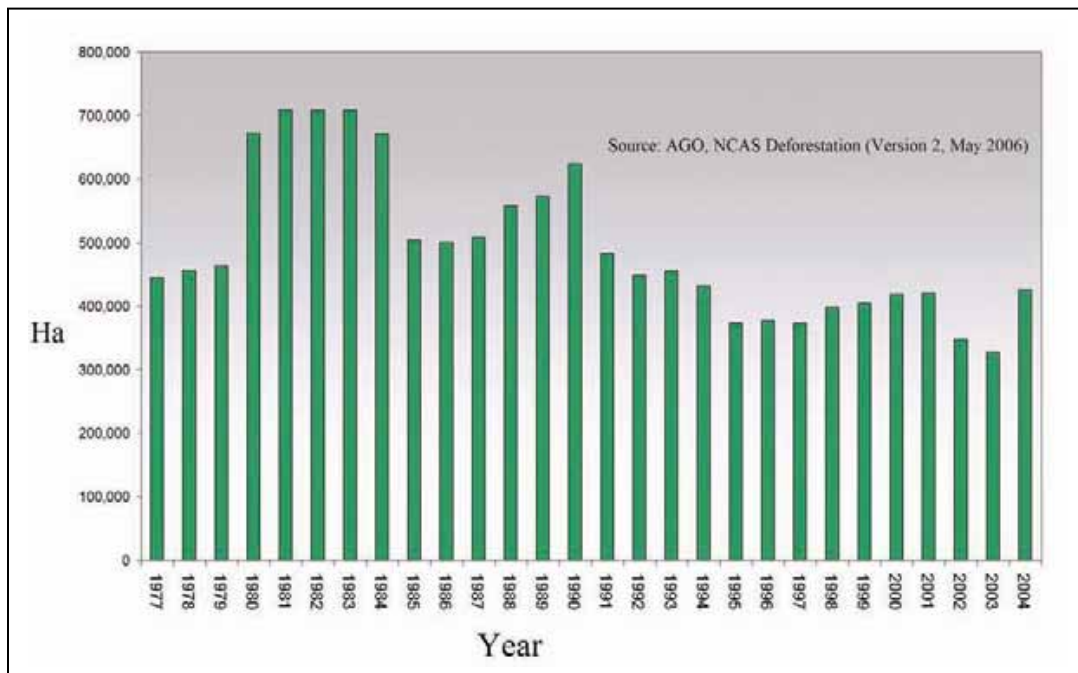


Fig.25, IBRA, 2006, Deforestation (www.environment.gov.au)

Fig.25 illustrates the National Deforestation from 1977 to 2004 as estimated by the National Carbon Accounting System (NCAS).

Information on change in Australia's forest cover is regularly being produced for the NCAS. It uses a consistent and regularly updated continent-wide interpretation of satellite data to estimate changes to allow carbon accounting. To date, the NCAS data has indicated a general reduction in annual deforestation since the 1980s and early 1990s, as indicated in the diagram. But the data does not currently report change in the extent of all native vegetation (non-forest vegetation). The most recent NCAS assessment shows that

deforestation in 2004 is estimated to be around 400 000 hectares around Australia. While this represents a very small proportion of Australia's native vegetation cover, the concentration of this loss of vegetation in particular areas suggests regional and local impacts on terrestrial biodiversity may have been significant. The rate of clearing amounts to almost one quarter of the deforestation rate in the Brazilian Amazon region (Australian Conservation Foundation, 2003).

As discussed, human activity has shaped and is still shaping the landscape of the more intensively settled places. The changes made to vegetation under European occupation drastically altered environments. As native flora disappeared and habitats were lost, the impact on the fauna was immediate. But there were also other threats to native species; intentionally and unintentionally introduced species of flora and fauna caused and are still causing impact on the native environment (e.g. rabbits, cane toads, cattle ticks, etc., skeleton weed, water hyacinth, scotch thistle,...). For many native species these introduced pests led to their extinction.

2.3. Land Use and Cultivation

Australia's area is around 770 million hectares, with about one quarter mostly desert and not used commercially. Early settlements tended to be established near reliable water supplies leading to Australia's population being concentrated along the coast, mainly in the comparatively fertile, well-watered east, south-east and far south-west. The establishment of irrigation schemes, largely by government, also played an important role in populating inland Australia. The discovery of the Great Artesian Basin in the eastern part of the continent provided reliable water for the pastoral industry in the dry inland grazing country (Australian Department of Agriculture, 2007).

After World War II, soldier settlement schemes existed, the terms of conditional purchase requiring that farmland be cleared with no official provision for the retention of shelter belts or riparian vegetation around drainage lines (Water and Rivers Commission Report, 1998).

Besides rainfall, which is the most important factor determining land use in Australia, it is obvious that soil types and properties are also fundamental, particularly in agriculture. A characteristic of the Australian landscape is that uncleared areas in the agricultural zone are often of poor soil. But areas with soils which are not highly suitable for agriculture are still likely to be farmed if other factors are favourable (www.environment.gov.au).

In some cases, soil limitations can be managed – for example, application of fertilizers to soils of low fertility, and use of conservation farming techniques on soils with high erodibility.

How the land resource is managed is closely related to its use and involves many issues such as land degradation, water use and quality, vegetation clearing and degradation, reduced biodiversity and impact of feral animals and weeds (www.environment.gov.au).

2.3.1. Extent of Land Use Areas

The following Fig.26, Land Use in Australia, indicates very clearly that agriculture is the major land use. Forestry tends to be confined to regions with higher rainfall. The built-up area is the most intensive used environment, occupying about 2,4 million hectares. It includes urban and periurban areas and open-cut mines (www.anra.gov.au).

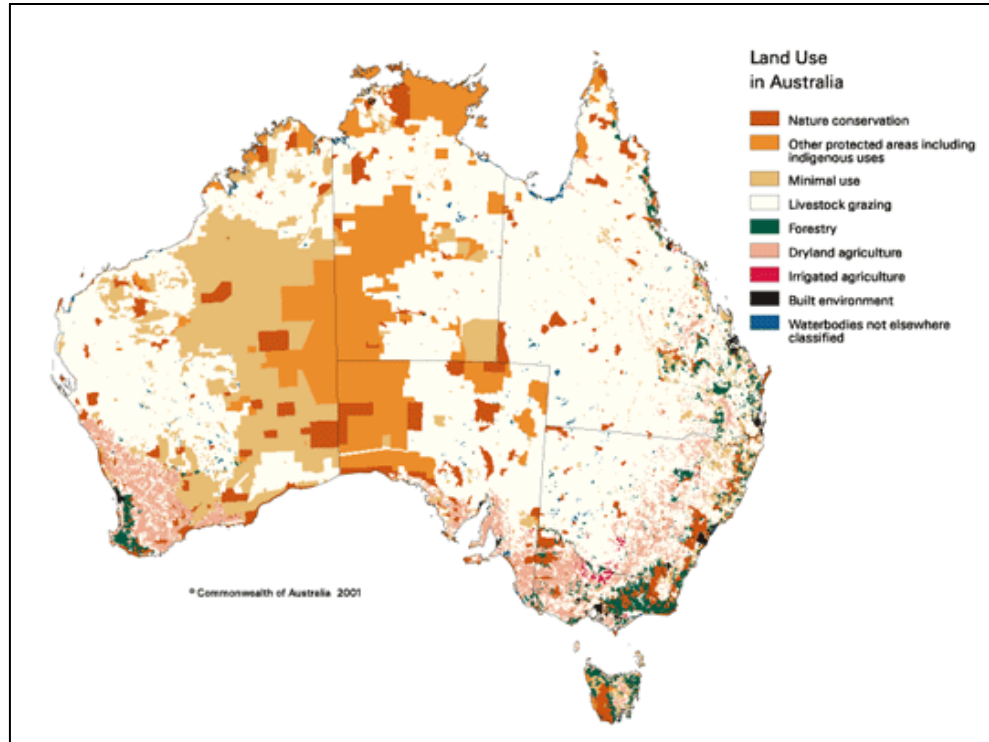


Fig.26, Australian National Resource Atlas, 2002 (www.anra.gov.au)

Land Use Description	Total Extent ('000 ha)	Total Extent (%)
No Data	187,4	0
Nature conservation	49 881,3	6,5
Other protected areas including indigenous uses	102 631,2	13,4
Minimal use	120 812,3	15,7
Livestock grazing	430 100,8	56,0
Forestry	15 187,0	2,0
Dryland agriculture	40 310,8	5,2
Irrigated agriculture	2 170,3	0,3
Built environment	2 442,4	0,3
Waterbodies	4 993,7	0,6

Fig.27, Australian Natural Resource Atlas, 2002

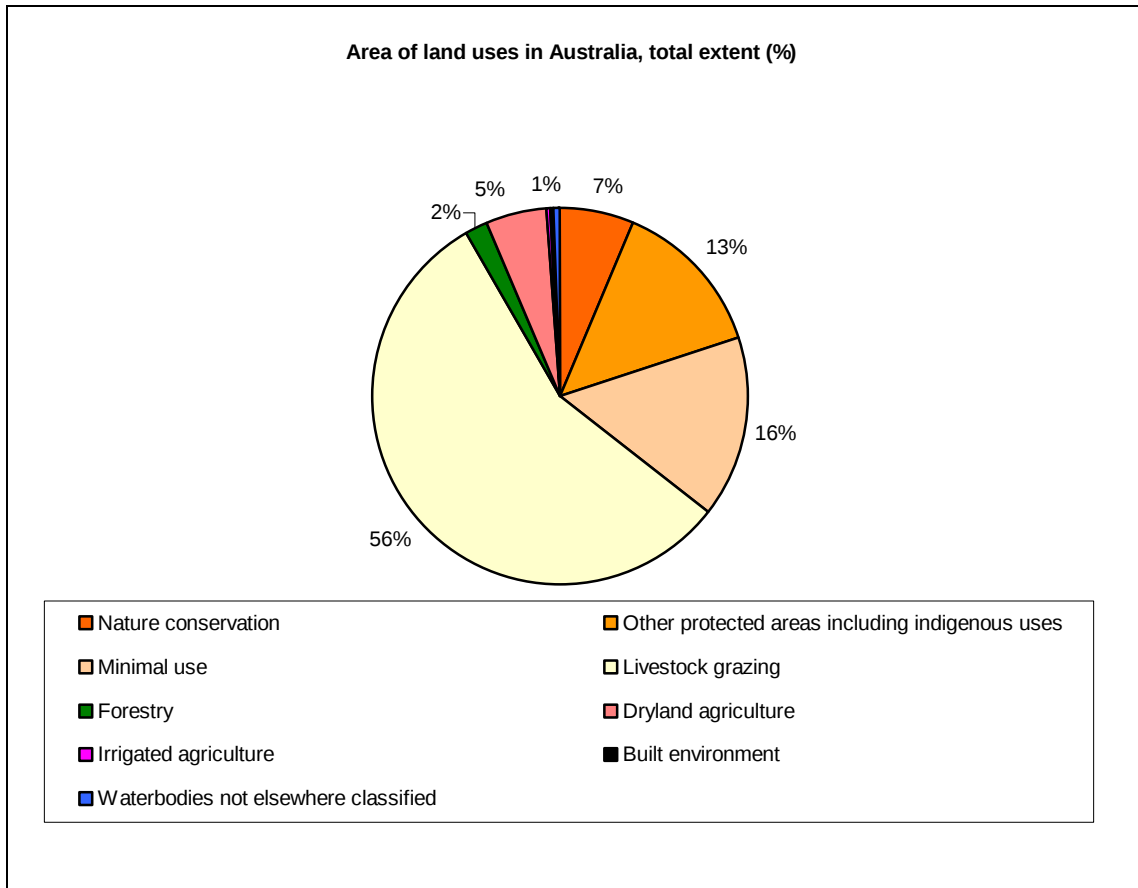


Fig.28, own illustration, based on Australian Natural Resource Atlas, 2002

Fig.26, Fig.27 and Fig.28 describe Australia's land use which shows the predominance of agriculture and here again livestock grazing, which takes up about 56% of Australia's landmass, mainly in arid and semi-arid regions, that is approx. 430 million hectares. In total the area of agricultural land covers nearly 62% of the country. With 120 million sheep, 24 million beef cattle (for meat) and 3 million dairy cattle (for milk) in 2000, Australian agriculture is predominantly livestock based. Agriculture was worth \$ 28 billion with \$ 11.9 billion from livestock industries, \$ 11.6 billion from cropping, and \$ 4.1 billion from horticulture (ABS, 2002). Although agriculture is still an important player in the Australian economy, mining, manufacturing, service and construction now contribute more to the economy than agriculture.

Intensive agriculture is concentrated on the coastal fringes of Australia and in the Murray-Darling Basin in the southeast. The produce from this Basin contributes around

40-45% of the total value of agricultural production. Cropping generates the highest output per hectare in dollar terms, accounting for about 40% (in years of drought) to 55% of the total value of agricultural production while occupying only 4.5% of agricultural land. Inland Australia, which is used mainly for grazing livestock, such as beef cattle, produces a lower value of output per hectare than crops (ABS, 2000).

In 2001, 287 513 Australians (1,5% of the population) were employed in agriculture on approx.145 000 farms (60% of farms with less than 500 ha).

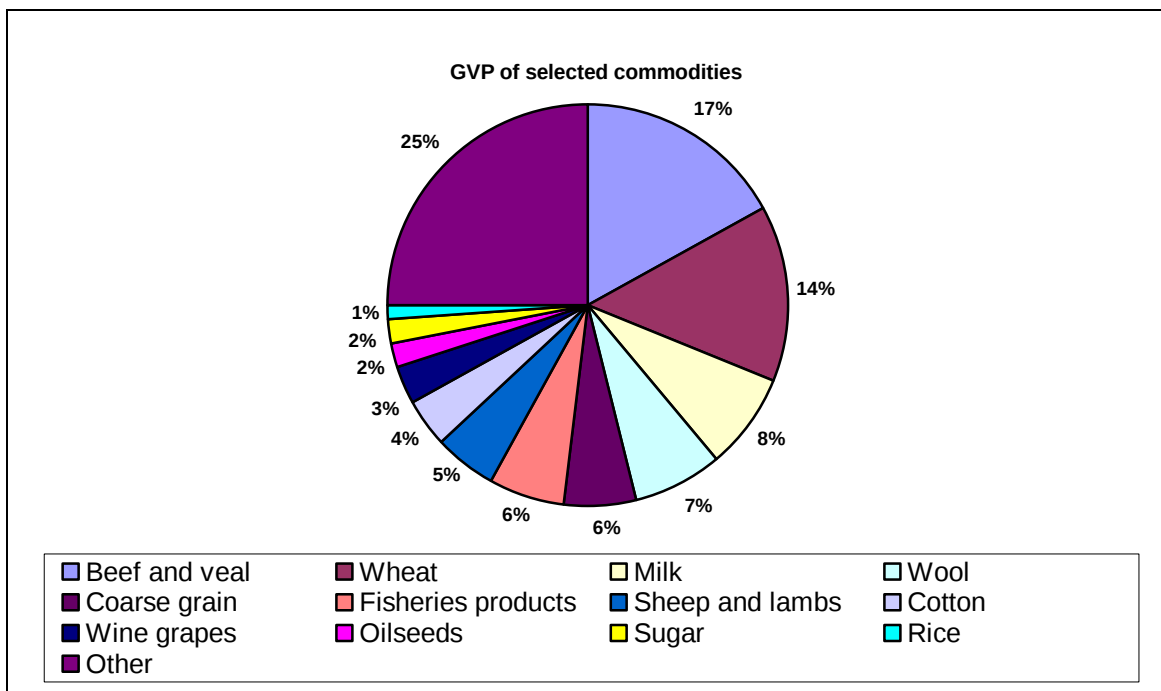


Fig.29, own illustration based on ABS 2003

Fig.29 shows the Gross Value of Production (GVP) of selected farm products, with wheat and other grains taking up 39% (the drought in the year 2002/03 caused a 20% drop from the previous year), followed by beef and veal production with 17% (ABS, 2003).

2.3.2. Agricultural Expansion

Australian agriculture has seen a marked increase in diversification and intensification of production, changing consumer preferences, improvements in handling, storage and distribution systems, enhanced breeding techniques and improved management practices.

Australian agriculture is a vital sector occupying a significant place in global rural trade, with wool, beef, wheat, cotton and sugar being particularly important (www.anra.gov.au).

There has been a steady expansion of agricultural activities for more than a century, with related increases in the use of irrigation, fertilizer and other inputs. For example, the area planted with crops, the agricultural activity which generates the highest per hectare returns, has more than doubled in the past 50 years; the nation's beef cattle herd has grown from just six in 1788 to 8.6 million in 1900, and to about 24 million in 2000. These activities and their steady increase are putting enormous pressure on the environment and the natural resources, even though beef cattle herd and the total area used for agriculture have declined from the peak levels reached in the 1970s and early 1980s, while the areas of crop and sown pastures have continued to grow, as sketched on the graphs below Fig.30a and 30b (ABS, 2003).

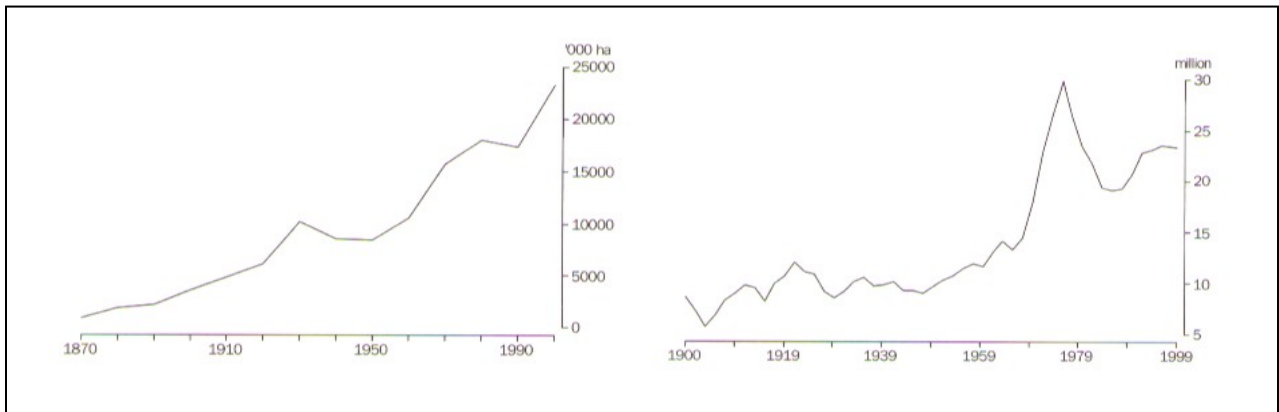


Fig.30a, Crop Area, 1870 to 2000, ABS 2003

Fig.30b, Beef Cattle Herd, 1870 to 2000, ABS 2003

The growth of crop land and sown pastures (for livestock) indicates a shift towards more intensive agricultural systems, producing more output with fewer inputs of labour, slightly more capital and a greater amount of knowledge. Use of inputs such as fertilizer has increased, as has the use of irrigation; even though excessive application of fertilizers can increase nutrient levels in waterways and increase levels of soil acidity, while irrigation may cause salinity and sodicity (ABS, 2003).

2.3.3. Distribution of Agricultural Land in Australia

Climate and soils play a major role where agricultural activities occur. As the driest continent in the world (excluding Antarctica), effective rainfall (where rainfall exceeds evaporation) is extremely important in Australia.

Most of the soils are naturally infertile and shallow, with deficiencies in phosphorus or nitrogen. Thus superphosphate and nitrogenous fertilizers are widely used. The choice of crop and pasture species within a farming system are also important to return nutrients to the system, maintain soil structure and minimize waterlogging.

Areas that have been cleared for crop and pasture production tend to coincide with five to nine months of effective rainfall per year. In areas with effective rainfall of more than nine months, generally only higher value crops or tropical crops and fruits are grown, where in areas with effective rainfall of less than five months, cropping is usually restricted to areas that are irrigated (Commonwealth Scientific and Industrial Research, 2004).

2.3.3.1. Australia's Agricultural Zones

2.3.3.1.1. High Rainfall Zone

- Occurs in a narrow strip along Australia's east coast, Tasmania and the south-west corner of Western Australia
- Rainfall relatively high (> 500mm annually) and reliable
- Fruit and vegetable growing and dairying are important in the south, while the growing of sugar cane, tropical fruits and vegetables are prevalent in the north
- The dominance of sown pastures allows high stocking rates of beef cattle throughout the region; it is generally too wet for sheep
- This highly productive coastal region occupy about 6% of Australia and includes all its major cities(www.anra.gov.au, 2008)

2.3.3.1.2. Wheat Belt

- Transitional zone between the continent's wet coast and its arid interior
- Produces almost all of Australia's cereal grain. Most farms also raise livestock. Wheat is grown throughout the zone, but in the south it is combined with sheep

farming and the growing of barley and oats. In the north, cattle are widespread, sorghum and oilseeds are also grown

- Livestock density in the wheat belt are lower than on the coast, particularly in the north where there are no sown pastures
- Under irrigation, the region produces fruit and wine grapes, and in the north cotton crops
- The wheat belt represents 14% of the continent's land area (www.anra.gov.au)

In 2006-07 Australian farmers produced around 11million tonnes of wheat for grain, a fall of 5% compared to the previous year because of a country-wide drought. 7,5 million tonnes were exported and 3,5 tonnes used for domestic purposes. In 2007 Australia was the sixth largest wheat exporter in the world (ABS, 2008).

2.3.3.1.3. Pastoral Zone

- Agriculture is restricted to the raising of livestock on native pastures
- Most of Australia's inland area (about 72% of the country) is too dry to sow pasture and crops. However, three quarters of this arid region has sufficient plant cover to support extensive grazing, provided groundwater is available
- Beef cattle are raised on huge properties in the north while sheep farming is dominant in the south
- In far northern Australia (8% of the continent), monsoonal rains allow vigorous growth of native grasses during the wet season. However, once the rain stops, these grasses dry very quickly and cease to be nutritious leading to very low cattle stocking rates (www.anra.gov.au)

The area allocated to different crops or land uses changes from year to year, depending on a range of environmental and economic factors. Environmental factors include the amount and timing of rainfall, minimum and maximum of temperatures and soil type. A key economic factor is the price paid for different types of agricultural products. For example, since the late 1980s the number of sheep has fallen, while the area planted with crops has increased, reflecting lower wool prices and a switch in land use from sheep

grazing to cropping. However the ratio can change any time, depending on the prices of grain crops and the wool world market (www.brs.gov.au).

The clearing of native vegetation for agricultural production has resulted in an imbalance in the natural groundwater systems. Annual and perennial crops and pasture collectively transpire less of the infiltrating rainfall than native perennial vegetation they have replaced. The resulting increase in rainfall infiltration has caused an increase in groundwater storage in areas where the groundwater flow rates are low, since discharge is less than the increase in recharge. Increased groundwater storage results in a rise in watertable levels. The rate of rise in the watertable has been monitored in some areas (e.g. in the southwest of the country) and shows an average of 10cm a year (ABS, 2004).

2.3.3.2. Irrigation

Water is vital for any kind of agriculture. About 70% of water used in Australia is for agriculture. In 2000 just over 2 million hectares of land were irrigated with 15.5 million megalitres of water. The water consumed by different crops varies, whereby vegetable growing achieves the maximum value of crops produced per megalitre of water used.

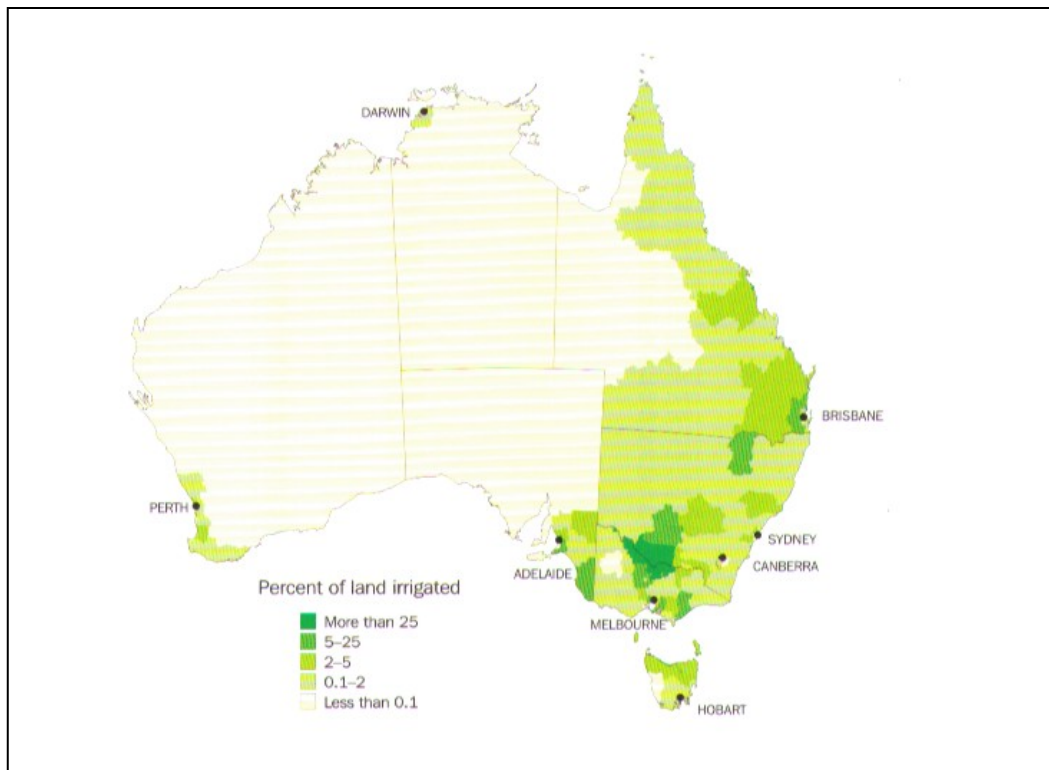


Fig.31, Agricultural Census ABS, 2001

On Fig.31 the irrigated intensive cropping areas especially in the Murray-Murrumbidgee Rivers Basins stand out clearly. Irrigation has diversified agricultural activities through intensive cropping and horticulture. Even though the success is tempered by the environmental costs of land and water degradation; here salinity is a particular serious problem. The farmland of today was once native vegetation, and significant changes in the flora and fauna of Australia have taken place since European settlement. In New South Wales, Victoria, South Australia, The Australian Capital Territory and Tasmania, half or nearly half of the native forests have been cleared (ABS, 2001).

2.3.3.3. Assessing Impacts of Future Climate Changes

A research on the impact of future climate changes has been undertaken by the CSIRO in 2001. Increase in carbon dioxide concentrations and temperature and projected changes in rainfall could have a significant impact on Australia's agriculture. However, predicting the likely impacts on these changes is complicated because increased carbon dioxide boosts plant growth and changes water use efficiency, while projected changes in climate can offset or enhance these benefits (www.csiro.au).

In dryland farming and grazing lands, where low rainfall often limits plant growth, higher carbon dioxide concentration may increase plant productivity. However, if warmer conditions are accompanied by rainfall decreases in key agricultural areas, particularly in winter and spring, the benefits of higher carbon dioxide levels will be limited. Indeed, productivity for some plants may be reduced (www.csiro.au).

Because projected changes in rainfall and temperature vary across Australia, it is important to assess regional impacts. The opportunities to adapt climate change via new crops, industries, and management practices will vary from region to region.

2.4. Impacts of Deforestation and Vegetation Modification

The impacts of land clearing and poor land management practices are widely distributed and seen all over the country. Besides the traces on the land surface the impacts on water quality are the most serious ones. Land clearing and agriculture has destroyed so much of the natural environment that it gets harder by the day to combat the consequences. The major water quality impacts of grazing and cropping industries relate to turbidity (haziness), dryland salinity, nutrients and pesticides. Grazing industries influence water quality (both surface and groundwater) through the effects of stock movement and pasture establishments which also promote soil erosion. Additional impacts can arise in cropping enterprises through tillage and harvest techniques and measures designed to remove unwanted plant residues -like burning stubble (www.environment.gov.au).

2.4.1. Weed Infestation

Besides the problems mentioned above there are some others like Weed Infestation. Weeds are plants that have established themselves outside of their natural range and are reproducing and now threaten the native flora and fauna. Most weeds were imported from other countries since European settlement for use in agriculture or as ornamental plants in gardens, e.g. Blackberry, Mimosa, Willows, Prickly Pear, etc. Some weeds impose substantial economic losses, while others cover very large areas, like Blackberries, which currently infest 10% (!) of Australia. Another weed, Paterson's curse, which was introduced to Australia in the 1840s from mail order catalogues as a garden plant cover now millions of hectares. Other non-endemic plants like the water hyacinth, originally from the Amazon River basin in South America, also posing a big threat for it can quickly choke waterways, reducing water flow, increasing evaporation and clogging irrigation systems (Water and Rivers Commission Report, 1998; www.anra.gov.au).

2.4.2. Monocultures

Here it is especially the Radiata pine which grows in large plantations, that occupy about 870 000 hectares in Australia (600 000 hectares pinewood); they form the backbone of the country's softwood industry. Most plantations grow on nutrient-deficient soils and production can decline with successive harvests. New plantations are increasingly being established on ex-pasture sites where unbalanced nutrition can result in poor quality wood. Monocultures are also a threat to the natural environment as they exhaust the soils and are especially prone to pests and other diseases that might spread to the native vegetation (ABS, 2004).

2.4.3. Destruction of Habitat

Most of the small mammals in the agricultural area are already gone because of non-native predators and the others are threatened by extinction through the destruction of their habitat. As native flora disappears and habitats are lost, the impact on the fauna is immediate. This extinction progression follows a classical cycle: mammals, reptiles, aquatic fauna, birdlife, flora. They track somehow parallel, somehow behind the introduction of non-endemic animals and plants, the fragmentation of habitat, the introduction of disease, such as the dieback virus, and rising salinity. Salinity is beginning to drive ecosystems to collapse (Australian Nature Conservation Agency, 1993).

2.4.4. Soil Degradation

Australia is covered by shallow old soils, susceptible to degradation by agricultural activities that deplete soil nutrients and damage soil structure. Soil degradation has resulted in losses to agricultural production and declines in the health of many native animal and plant population right through to extinction.

As a comprehensive biological survey of Western Australia's agricultural zone's shows that of 4000 plant species, 450 are in danger of extinction because of soil degradation and saline groundwater. Of that 4000 species, 850 are found only in fresh or naturally saline lowlands, which are directly threatened by rising ground water and salinity (Department of Conservation and Land Management, 1996; Schoknecht, 2004).

Three types of land degradation - **Soil Acidity, Sodicity and Salinity** – have been estimated to cost the Australian economy at least 2.5 billion dollars annually.

2.4.4.1. Soil Salinity

This presents the biggest problem. Estimates of the costs of land degradation vary greatly because of the difficulties involved in measuring the costs and the range of costs considered. Such as: damage caused to public and private assets; expenditure needed to rehabilitate degraded land; value of production that could have been gained from the land, were it not degraded. This problem will be dealt with in the following chapters (National Land and Water Resources Audit, 2001).

2.4.4.2. Soil Acidity

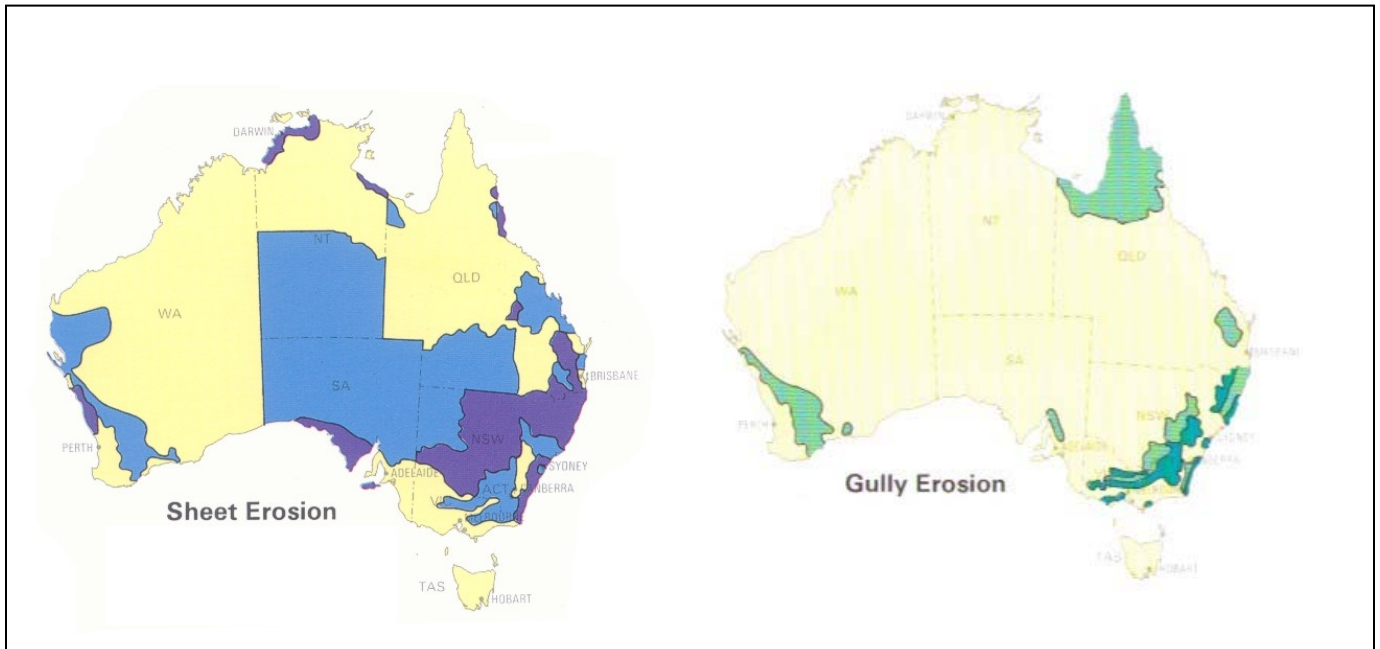
The acidity in the soil often occurs naturally, but it is also increased by applying acidic nitrogen fertilizer, especially on sandy soils with less than 500mm rainfall per year (www.csiro.au).

2.4.4.3. Soil Sodicity

Sodicity is often found in conjunction with other land degradation problems, particularly waterlogging and gully erosion. Soils are classified as sodic when the level of sodium (Na) begins to affect the soil structure. Sodium is attached to clay in soil that affects soil structure and can lead to clogged pores, which again leads to waterlogging.

2.4.5. Erosion

At least 30% of Australian farms experience some form of land degradation. One other serious problem caused by land clearing is erosion. Destroying forests and woodlands open the soil for erosion and long-term change in groundwater levels. Soil erosion occurs on all soil types; with some of the lighter soils, having a non-wetting tendency, running water during storms cause erosion. Some of the clay soils are highly dispersive and will form deep gullies. Sheet and gully erosion have reduced the value of many already poor soils as seen in Fig.32 a and Fig.32 b (Australian Surveying and Land Information, 2004). Bare soils and heavily grazed areas are also prone to wind erosion. In many areas, up to a metre of topsoil has been lost.



Sheet Erosion:

Dark blue: high proportion of rural land subject to sheet erosion

Light blue: average proportion of rural land subject to sheet erosion

Gully Erosion:

Dark green: high proportion of rural land subject to gully erosion

Light green: average proportion of rural land subject to gully erosion

Fig32a, Sheet Erosion

Fig32b, Gully Erosion

Australian Surveying and Land Information, 2004

Sheet erosion, Fig.32a, can be found in most of the agricultural areas where there are no obstacles in the way, like trees, shrubs or native grasses. It is generally produced by cloudbursts, when loose soil particles are moved down-slope by broad sheets of rapidly flowing water filled with sediment, known as sheetflood.

Gully erosion, Fig.32b, results when water flows along linear depressions, eroding trenches. This is particularly noticeable when rural roads lie lower than the surrounding farmland. These gullies or trenches build a channel for water flows which enables the water runoff to carry away large amounts of soil and sediments. That also occurs in the intensively used farming districts (Australian Surveying and Land Information, 2004).

3. Salinity in Australia's Ecosystems

3.1. Present Situation

Salinity has been known in Australia for more than 100 years. Since some areas of the continent have naturally salty soils some salinity problems in particular areas may predate land clearing. In agricultural areas the level of salinity can increase through the removal of trees, the use of irrigation or both. Salinity accelerates the decay of plumbing, roads and buildings, and increases the risk of flooding in addition to stopping plants from growing and hence reducing agricultural production. It also can increase the extent of soil erosion and collapse of stream banks (Australian Conservation Foundation, 2005).

Since 1788, the first white settlement, nearly half of Australia's native bushland has either been cleared or significantly degraded in some way (e.g. overgrazing with cattle), disturbing or completely clearing substantial areas of wildlife habitat. In fact, continued clearing of native bush is probably the biggest single threat to Australia's natural heritage and the damage will continue to unfold for decades after the clearing stops (Commonwealth Scientific and Industrial Research, 1994).

Approximately 70% of Victoria, for example, has been cleared for farms, towns, and other uses. It is not unusual in many parts of southern Australia for upwards of 90% of a catchment to have been cleared, leaving only a few remnant patches of native habitat in a 'sea' of agriculture, houses and roads. Unfortunately, much of the clearing has occurred and continues to occur in areas of high salinity hazard, increasing the risk of salinisation (Australian Conservation Foundation, 2005).

Today, about 2.5 million hectares of agricultural land in Australia is already affected by salinity and there is the potential for this to increase to 15 million hectares. Much of it is Australia's most productive agricultural land. The area damaged by salinity to date (CSIRO, 2005) represents about 4.5% of present cultivated land. The current costs of the damage amount to \$ 130 million annually in lost agricultural production; \$ 100 million

annually in damage to infrastructure and at least 40 million in loss of environmental assets.

3.1.1. Critical Limits of Land and Stream Salinity

Soil salinity becomes a problem when the concentration of salts within the soil and water bodies exceeds the tolerance limits of native and introduced plants. Each species has different tolerance to salinity. Salt-affected soils may still be productive, although at lower yields, using salt-tolerant crops and pastures.

In agriculture, salinity is considered severe when the yield of the preferred crop or pasture is reduced by more than 50% and moderate when the yields are reduced by between 10 and 50%. For water resources, salinity is severe if the water can no longer be diverted for beneficial use and moderate when it imposes additional costs (e.g. mixing of water sources, damage to infrastructure). For natural environments, salinity is significant if it modifies terrestrial or aquatic ecosystems. In its most severe form, natural plant and animal communities are either destroyed or replaced by salt-tolerant species (www.csiro.au).

3.1.2. Severity of Salinity

The severity of salinity can be assessed using soil and water samples, visual and plant indicators, geophysical equipment and groundwater observation wells. Water considered desirable for drinking should have a total soluble salt (TSS) content of less than 500 mg/l. Salt-sensitive plants die and salt-tolerant plants become dominant when the conductivity of the root zone exceeds 100 mSm (EC) and the watertable is within one or two metres of the surface for most of the year. Soil is usually considered saline when the electrical conductivity of a field sample exceeds 400 mSm (EC) or the terrain conductivity measured in the field with geophysical instruments exceeds 50-70 mSm (EC) (CSIRO, 2007).

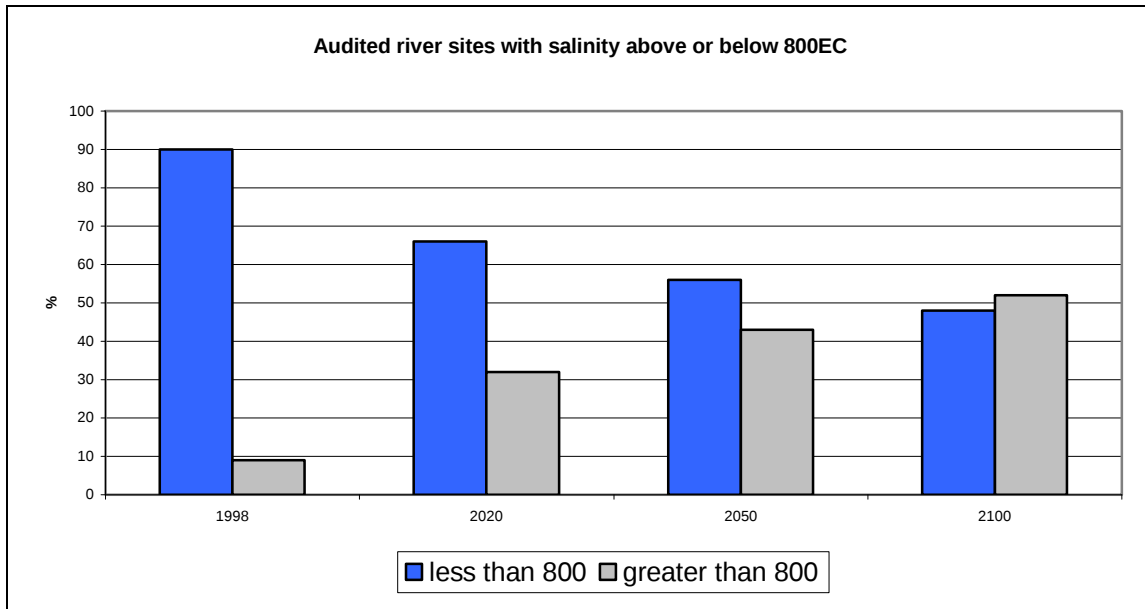


Fig.33, ABS, 2001

The diagram, Fig.33, emphasizes the predicted rapid increase in water salinisation from 1998 to 2100. Salinity levels below 800 EC will decrease to less than 50% in 2100. This will put enormous stress on available drinking water resources for man, animals and plants.

The world health organization standards set the upper limit of salinity for drinking water at 800 EC. At 1 500 EC units, irrigation of rice, maize and grain crops should not take place and irrigation of leguminous pasture and forage crops is also risky. A water body which registers a salinity level of 5 000 EC units is classified as saline (ABS, 2001).

What are milliSiemens per metre? (mS/m)

These are the standard units of measure of bulk soil conductivity taken at 25 degree Celsius. A Siemens is a measurement of a material's conductance. Expressing the value in milliSiemens per metre removes the volume from the equation, just as a material's density is independent from its volume. An Ohm is a measure of resistance, while Siemens are a measure of conductance. In some scientific literature the electric measurements of the soil are expressed in resistivity – or ohm-metres (Encyclopedia Britannica, 2002).

3.2. Natural causes of salinity

Salt is a natural feature of much of the Australian landscape; vast quantities of salt being the inheritance of an old, dry and relatively flat continent. Much of the southern mainland landmass was once covered by ancient seas, long since retreated, leaving behind large deposits of salt which partly comes to the surface with the slow, steady weathering of rocks. Salt is distributed widely across the Australian landscapes for it also originates from deposits of oceanic salt drifted in with rain and wind. Small increments of salt have accumulated over millions of years in an environment where evaporation generally exceeded rainfall and where much of the drainage led only towards the centre of the continent (Ollier, 1988). Over eons this salt in the landscape has moved around in response to changes in climate. For example, during the glacial retreat ending the most recent ice age, large volumes of salt were blown over and re-deposited in the Murray-Darling Basin. Unlike most other countries, the distinctive flatness of much of Australia, combined with a low average rainfall and high rates of evaporation, mean that groundwater moves sluggishly and is slow to flush the country clean of salt (National Land and Water Resources Audit, 2000).

Today rain is still distributing salt on the continent. In streams in the southwest, for example, the main component of the salt is sodium chloride from rainfall and dry fallout from the prevailing winds. The chloride concentration in precipitation decreases with increasing distance from the coast. Rainfall salinities are typically in the order of 10 –20 milligrams per litre or 20-200 kg/ha/year. Most of the salt fall is washed into streams quite quickly. The salt balance of a catchment area subject to agricultural clearing is changed from a state of equilibrium or accumulation to a state of net salt export. Approximately 1000 years are required in low rainfall areas to leach the salt from the soil and to return the stream salinity to low levels generated by atmospheric input (www.audit.ea.gov.au).

Salt stored in the soil or groundwater is concentrated through evaporation and transpiration by plants. In a healthy catchment, salt is slowly leached downwards and stored below the root zone, or out of the system (WA Department of Agriculture, 1997).

The natural environment has accommodated this salt - Australia is having about 29 million hectares of primary salinity – land that is naturally saline. Salt lakes that have been present since before the land was cleared for agriculture characterize some of it (Fig.34).



Fig.34, Lake Eyre/South Australia, photo by author, 1983

Australia really is a fragile place. Much of the native vegetation – trees, shrubs and grasses – has evolved to cope with the country’s typical dryness and poor soil fertility. The native plants do this by way of roots penetrating deep down into the soil in search of water. In the past – before European colonization, agriculture and cities – native plants would take full advantage of precious rainwater before it percolated past the reach of their roots, thus recharging the groundwater (Water Authority of WA, 1988).

Salinity was first noticed in the 1850s. During the First World War, Western Australian scientists warned of the dangers of clearing parts of the landscape. But today, decades after learning about the dangers of salinity, Australia is still allowing vast parts of the country to be cleared. Over a quarter of Australia’s bioregions is subject to continued clearing. In fact, Australia used to clear more native bush every year than any other developed nation on earth and only four developing countries – Brazil, Zambia, Indonesia and the Sudan – cleared and are still clearing more than Australia. Most years Australia is still destroying 600 000 hectares of the country’s native forest, woodland, scrubland and grassland. Scientists believe that much of this clearing, most of it in Queensland, New South Wales and Tasmania, will lead to still more salt damage and other kinds of land and water degradation, biodiversity loss and extra greenhouse gases in the atmosphere (www.anra.gov.au).

3.3. Man-made Salinity

In contrast to native plants, most introduced crop and pasture plants are annual and shallow rooted, meaning that much more water now enters the soil and leaks past the roots into the groundwater system than drains away, as seen in Fig.35. Ways of farming the land that in other parts of the world are more or less sustainable are apt to cause salinisation under Australia's unique conditions. In the relatively short stretch of time since Europeans arrived on the continent, large-scale clearing of native vegetation has meant that ancient groundwater systems have swung out of balance and large amount of salty water have risen to the soil surface (Australian National Dryland Salinity Program, 2001).

A comparison of water use in native vegetation and cleared agricultural land:

	Native vegetation	Cleared agricultural land
Rainfall	370 mm	370 mm
Run-off	0 mm	18 mm
Evapotranspiration (soil and leaves)	359 mm	319 mm
Interception loss (wet leaves)	11 mm	7 mm
Rainfall to groundwater	0 mm	26 mm

Fig.35, Journal of Agriculture 2000

3.3.1. The Salty Cycle of Destruction

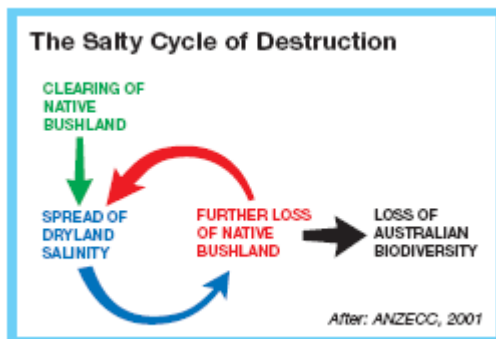


Fig.36, www.environment.nsw.gov.au

- Stage 1 With the clearing of native vegetation – woodlands, forests, shrublands and grasslands - a vicious cycle unfolds in which the balance of water in the landscape is upset and ancient deposits of salt are brought closer to the surface as seen in Fig.36.
- Stage 2 These salts are damaging more bushland, spreading salinity still further and causing –
- Stage 3 Further loss of native vegetation and the irreversible loss of Australia’s unique biodiversity. As salt levels rise they cause the loss of shelter and nesting sites for wildlife, loss of food sources, decline in drinking water, competition with weeds and pests that can tolerate higher salinity levels (www.environment.gov.au).

3.3.2. Model of Hydrology Processes

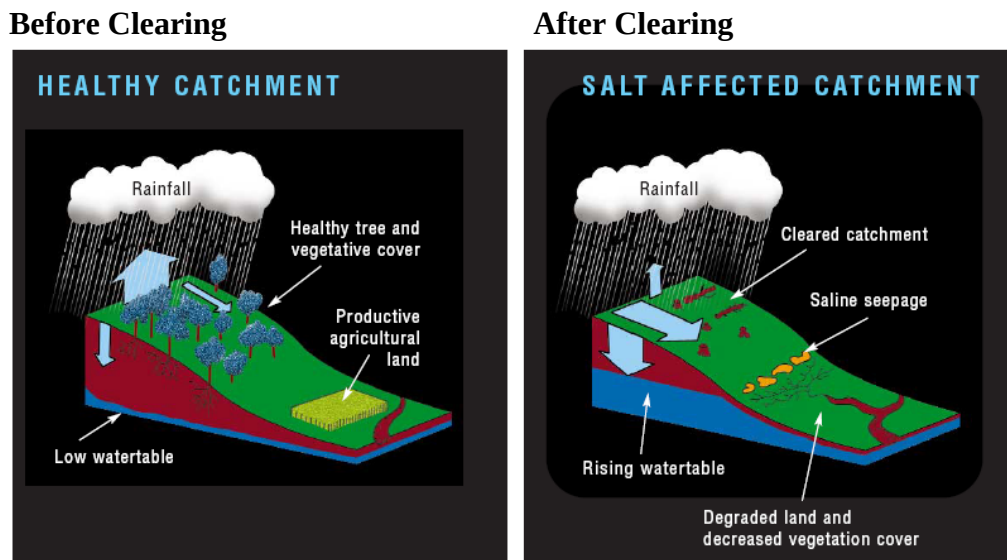


Fig.37, www.cmis.csiro.au

The above Fig.37 is a basic model of catchment hydrology showing how the destruction of deep-rooted perennial native vegetation in one area can bring about salinisation quite some distance away. The precise picture of disturbed groundwater systems, waterlogging and salinity varies across Australia, but the basic cause of dryland salinity, land clearing, remains the same (Department of Environment and Water Resources, 2007).

Lower lying parts of the landscape, including rivers, wetlands and valleys, are those areas where dryland salinity typically shows up first. Even though much more land contains salt leached into the soil profile (above the water table) than can first be detected for it can no longer be seen at the surface. Some of this salt has leached into the groundwater systems and continues to do so, gradually reappearing lower in the catchment area as saline surface, or it seeps into the baseflow to streams, rivers and lakes (Fig.38, saline river in the country's southwest) (Johnson, 1994).

Often the discharge zone lies at a considerable distance from any cleared recharge zone, although the zones of recharge and discharge can be right on top of one another. It is not unusual for one landholder to clear native vegetation on their property and, depending on the soil type and situation of the land, the salt may turn up on a neighbour's property or in a distant wetland kilometres away. There is often a long time lag of years to decades between stripping the land of native bush and the point at which the damage becomes obvious. Unless tracks are kept of changes to the watertable, the changes are usually not noticed until it is too late (Dent, 2000).



Fig.38, Saline stream near Quairading, southwest Western Australia, NDSP, 2001

3.4. Types of Salinity

Two broad forms of salinity are recognized in Australia (www.csiro.au, www.anra.gov.au, www.abs.gov.au).

3.4.1. Primary Salinity

Primary salinity or naturally occurring salinity is part of the Australian landscape, and reflects the development of this landscape over time. Examples are the marine plains found around the coastline of Australia and the salt lakes in central and western Australia.

3.4.2. Secondary Salinity

Secondary salinity is the salinisation of land and water resources due to land use impacts by people. This is the most severe form of salinity which is human induced and threatening the landscape.

We subdivide secondary salinisation into dryland and irrigation salinity, according to their origins. Irrigation salinity is confined to a relatively small area of the continent whereas dryland salinity poses a big threat to agriculture, waterways, biodiversity, infrastructure.

3.4.2.1. Irrigation Salinity

It typically occurs when the amount of water applied through irrigation is greater than the amount needed by the crops. One example: in the Murrumbidgee Irrigation Area (MIA) in southern New South Wales, watertables have risen from a depth of 25 metres before irrigation began to the situation today where the biggest part of the MIA has a watertable at a depth of 2 metres or less. Wet winters in areas with such shallow watertables can quite suddenly tip the balance. Like in the 1970s when a big area of irrigated land went out of production due to the rapid onset of waterlogging and salinisation (www.csiro.au/swagsim, 2002).

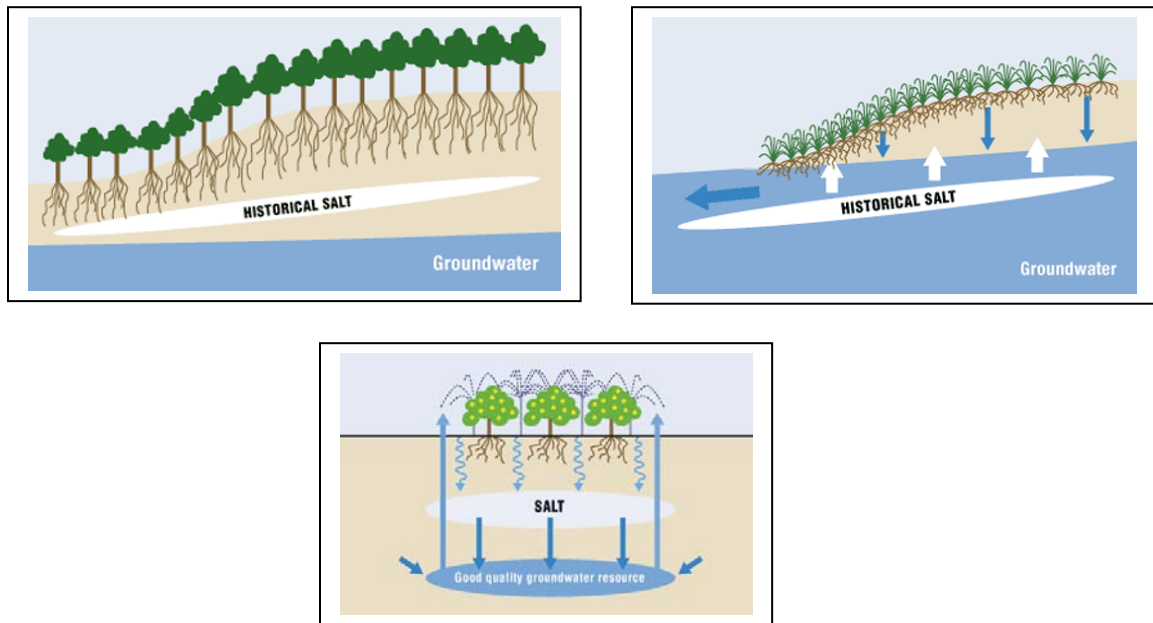


Fig.39, www.napswq.gov.au

In Fig.39 the different levels of water tables with their respective surface vegetation cover is illustrated. Additional irrigation water causes the underground water table to rise, bringing salt to the surface. When the irrigated area dies and the underground watertable recedes, salt is left on the surface. Each time the area is irrigated this salinity process is repeated.

All irrigation water, however ‘sweet’, contains some salts. For example, assuming irrigation water with a low salt concentration of 0,3 g/l (equal to 0,3 kg/m³ corresponding to an electric conductivity of about 0,5 dS/m) and a modest annual supply of irrigation water of 10 000 m³/ha (almost 3 mm/day) brings 3 000 kg salt/ha each year! (Ive, 2000).

Both dryland and irrigation salinity can increase the amounts of dissolved salts entering adjoining rivers and streams. The manipulation of rivers, dams and lakes can also increase waterway salinity by changing natural surface water and groundwater flows.

Irrigation salinity is much easier to bring under control and to contain within a specific area than dryland salinity (Murray Darling Basin Ministerial Council, 1999).

3.4.2.1.1. Irrigation Salinity Control

To control irrigation salinity CSIRO Land and Water has developed an innovative and simple tool that can be used to improve irrigation efficiency and stop over-irrigation. This device is called the '**FullStop**', because it does just that by indicating when the soil is 'full' and the irrigation should stop.

The FullStop - automatically accounts for rain and water use since the last irrigation
it stores a water sample that can be analysed
it is simple and inexpensive

The FullStop (a funnel-shaped container, which can be buried in the root zone) was developed for use in irrigated agriculture. When an irrigation event takes place, a wetting front moves through the soil – the speed of which is determined by the moisture in the soil. The moment the wetting front reaches the FullStop, water collects at the base of the funnel and an electric float switch is activated (Hutchinson, CSIRO, 2000).

By placing several devices at different locations within a paddock, a farmer can tell when wetting fronts have reached the root zone in different areas. The detectors can be connected to a conventional irrigation controller, ensuring the water supply is switched off once the wetting front has triggered a certain number of FullStop devices. The information gathered can also be used in irrigation schedules, ensuring water wastage is kept to a minimum.

This FullStop device can also be used for domestic purposes. In home irrigation systems, the FullStop can be wired in series with an electrical water solenoid that stops the irrigation automatically when the soil is saturated.

This FullStop not only saves people money because they are not over-watering, but it also reduces their contributions to rising groundwater levels (CSIRO Land and Water, Oct.2000).

3.4.2.2. *Dryland Salinity*

It occurs where native vegetation is cleared from the land for broad acre farming or grazing. This type of salinity is far more widespread but, in both types of salinity, water imbalances are the underlying cause.

The fundamental cause of salinity is changes in the flows of water entering and leaving the underground water supply. If the amount of water entering the ground increases or the amount of water leaving the ground decreases, then underground water rises closer to the surface. This is called a rising water table. As the water rises it carries dissolved salts with it. This saline soil and the water stop some plants from growing and kill others outright. Many crops cannot be grown in saline soils. Where salinity is severe, salt is deposited on or near the surface as water evaporates. Run-off from saline areas can carry salt to rivers where it is transported to other areas. This secondary salinity usually occurs when there is a saline water table within 1.2 – 1.8 m of the ground surface. The critical depth may be greater in some loams, and less in coarse to medium sands and some heavy clays. Severe salinity usually occurs when a saline water table is present within 0.5 m of the ground surface in late spring (Loveday, 1993; Martin, 1998; Stirzacker, 2000).

Both forms of salinity are therefore due to accelerated rising water tables mobilizing salt in the soil. There is no fundamental difference in the hydrologic process.

Stream salinity refers to the situation where there is a concentration of dissolved salts in stream (or river) water. Although most current examples of stream salinity are directly associated with secondary salinity in the catchment area, there were streams (just like lakes) that were saline before clearing commenced (www.napswq.gov.au).

3.5. Areas at Risk

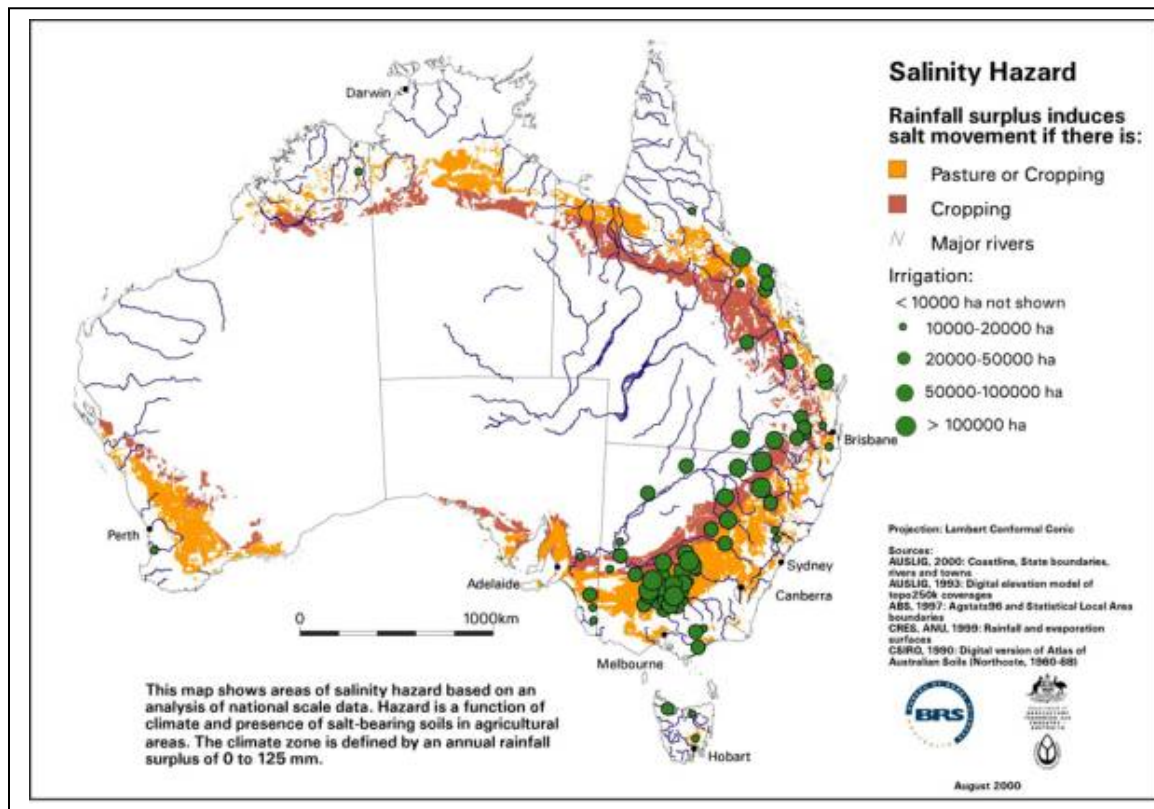


Fig.40, www.affa.gov.au

Fig.40, the map showing areas of salinity hazard, contains almost all agricultural regions around Australia. The wheatbelt in southwest Western Australia is already most affected by salinity, as well as the Murray-Darling Basin which extends from Queensland through New South Wales, Victoria and South Australia (www.affa.gov.au).

The national Land and Water Resource Audit's dryland salinity assessment has in collaboration with the States and Territories, defined the distribution and impacts of dryland salinity across Australia. The aggregate values presented below are the best available estimates within the limits of the methods and data used by the State, Territory and research agencies which undertook this risk assessment.

3.5.1. Areas (ha) with a High Potential to Develop Dryland Salinity in Australia

(Australian Natural Resource Atlas, 2000)

State/Territory	1998/2000	2050
Tasmania	54 000	90 000
New South Wales	181 000	1 300 000
South Australia	390 000	600 000
Queensland	not assessed	3 100 000
Victoria	670 000	3 110 000
Western Australia	4 363 000	8 800 000
Total	5 658 000	17 000 000

Fig.41, www.anra.gov.au

(Northern Territory and Australian Capital Territory are not included in this table because of their low risk). Fig.41 lists the extent of areas at high salinity risk according to their state.

- The bulk of non-agricultural areas in Western Australia, South Australia and western New South Wales were considered to have a very low salinity risk and were not assessed.
- Approximately 5.5 million hectares are within regions mapped to be at risk or affected by dryland salinity. It has been estimated that in 50 (?) years time the area of regions with a high risk may increase to 17 million hectares (three times as much as at present) (www.affa.gov.au).
- Some 20 000 km of major road and 1600 km of railway occur in regions mapped to have areas of high risk. Estimates suggest these could grow to 52 000 km and 3 600 km respectively by the year 2050.
- Salt is transported by water. Up to 20 000 km of streams could be significantly salt affected by 2050 (www.anra.gov.au).

- Areas of remnant native vegetation (630 000 ha) and associated ecosystems lie within dryland salinity risk areas. These areas are projected to increase by up to 2 million ha over the next 50 years.
- Australian rural towns are not immune: over 200 towns could suffer damage to infrastructure and other community assets from dryland salinity by 2050.

Rising saline groundwater is causing increasing contamination of farm dams, and leading to increased discharge of saline groundwater into streams and lakes. Inland lakes that formerly contained intermittent fresh water have become semi-perennial and saline (Water and Rivers Community Report HM, 2/1998).

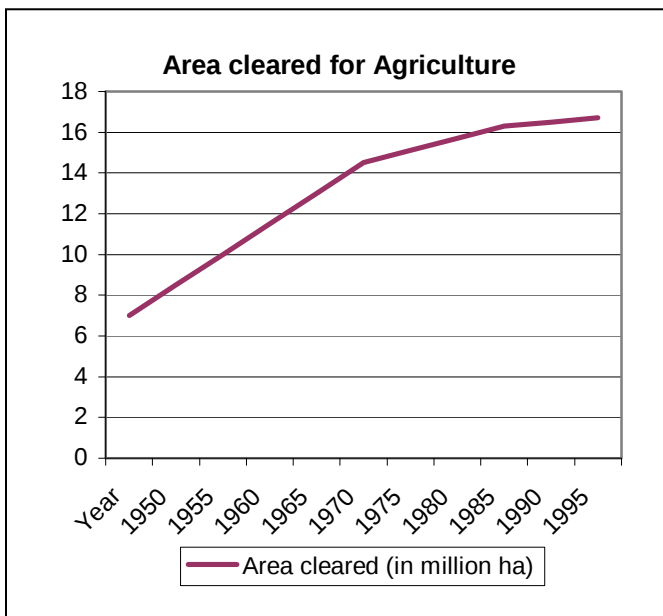


Fig.42a, own illustration based on ABS, 2003

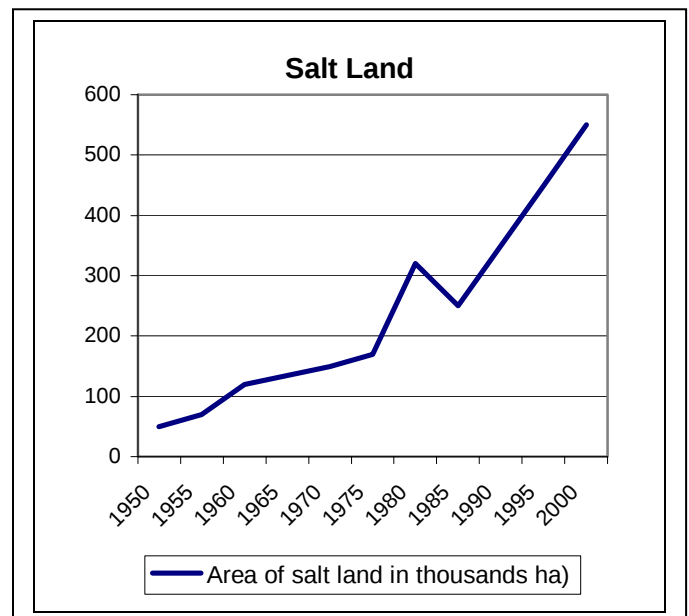


Fig.42b, own illustration based on ABS, 2003

The two graphs, Fig.42a and 42b, compare the area cleared for agriculture in Western Australia and the area affected there by salinity. The area of saltland has increased at a rate of about 11 000 ha a year from 1955 to 2000, the area cleared for agriculture has more than doubled over the same period, although the rate of clearing is falling.

3.5.2. Groundwater Trend in Southwest Western Australia

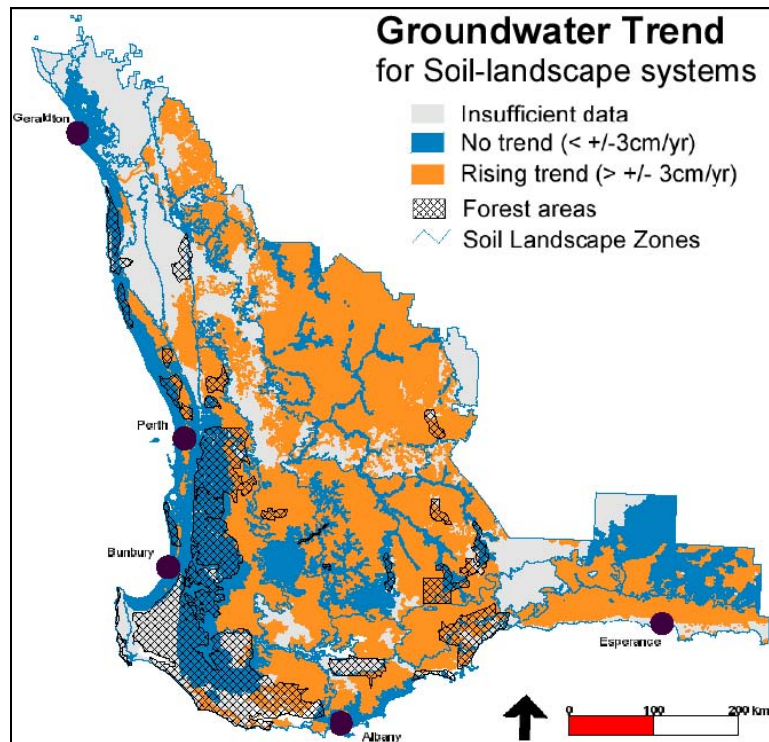


Fig.43, Groundwater trend in the SW of Western Australia, Short and McConnell, 2000

Rainfall statistics by the Western Australian Bureau of Meteorology, have shown that over much of the agricultural regions total winter rainfall (May-October) has decreased, while the warmer months show a small increase. Annual totals have generally been declining between 5 and 30 mm per decade over the southwest agricultural regions between 1910 and 1997 (Bureau of Meteorology, 2000).

Based on these precipitation statistics the rate of the rising groundwater trend (Fig.43) represents the minimum rate expected based on rainfall alone and disregarding any change in land use. Should the average rainfall increase, the rate might also increase and accelerate the impacts of salinity (Short and McConnell, 2000).

The clearing of native vegetation and replacement by annual crops and pastures has led to a substantial increase in recharge to the groundwater system. Other contributing factors include high salt storage in the soil and the presence of shallow bedrock that acts as a barrier to groundwater flow. As a result of increased salinity levels in water bodies, diversity of aquatic life can decrease and fringing vegetation can be adversely affected. This allows the successful invasion of salt-tolerant environmental weeds.

3.5.3. Groundwater Flow

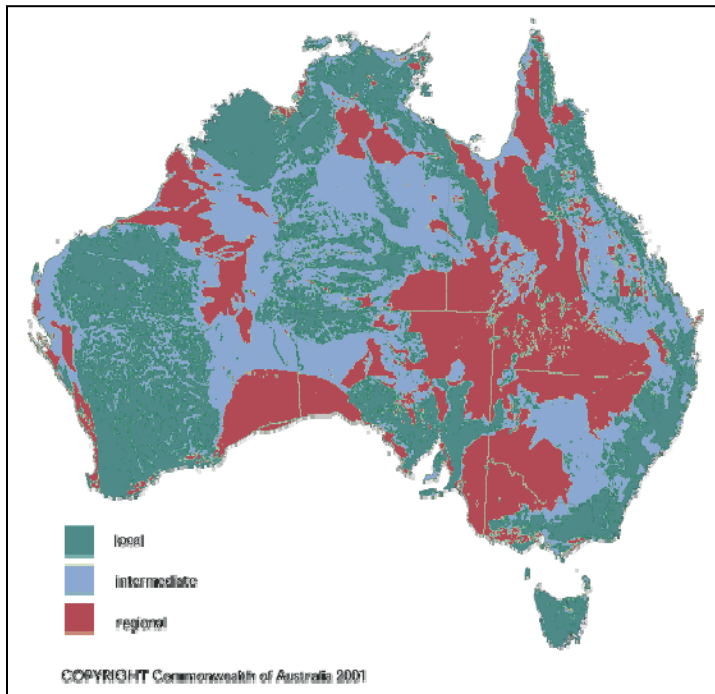


Fig.44a, NLWRA, 2004

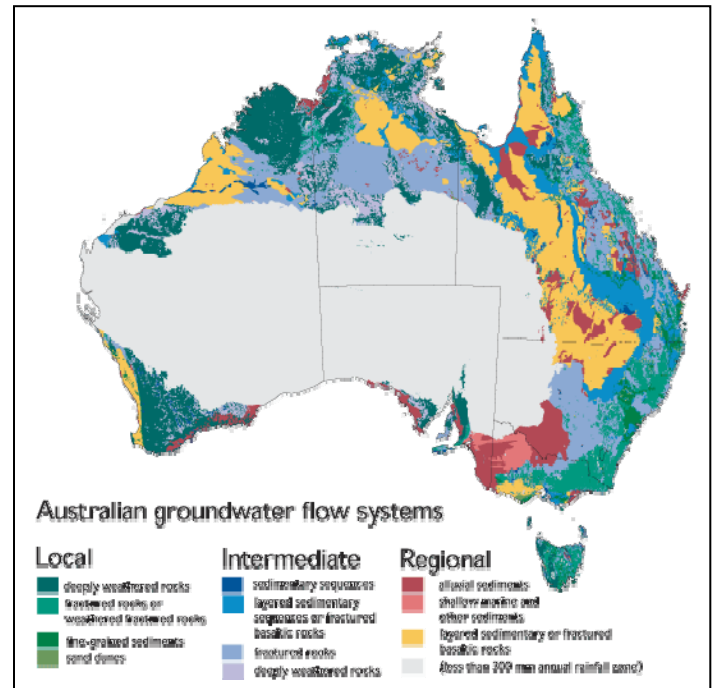


Fig.44b, NLWRA, 2004

The two maps above, Fig.44a and 44b show the character of groundwater flow systems distributed across Australia. Groundwater flows have been classified into three broad types of systems:

3.5.3.1. Local Groundwater Flow System

These three systems respond differently to agricultural and salinity practices. In areas where local groundwater flow systems are prominent (biggest part of Western Australia, Tasmania and parts of Southern Australia and eastern New South Wales), water tables and salinity discharge could be expected to rise within 20 to 30 years of initial agricultural development (NLWRA, 2000; www.nlwra.gov.au). These systems also usually respond relatively rapidly to salinity management practices.

3.5.3.2. Intermediate Groundwater Flow System

Areas that are dominated by intermediate groundwater flow systems, such as the Murray-Darling Basin and throughout Western Australia and the Northern Territory, have a greater storage capacity and generally higher permeability than local systems. Here it typically takes up to 50 to 100 years after initial agricultural practices for salinity to become evident. The extent and responsiveness of these groundwater systems present much greater challenges for dryland salinity management than local groundwater flow systems.

3.5.3.3. Regional Groundwater Flow System

Finally, in areas with regional groundwater flow systems, saline discharges are not expected until 100 years after agricultural practices commence in that area. They take much longer to develop increased groundwater discharge than the other two systems. The full extent of change may take up to thousands of years. The scale of regional systems is such that farm-based catchment management options are ineffective in re-establishing an acceptable water balance. These systems require widespread community action and major land use changes to secure improvements to water balance (Coram, Dyson and Evans, 2001).

3.5.3.4. Assessment of the 12 Sub-types (www.nlwra.gov.au)

Groundwater processes in Perth and Bremer Basins in Western Australia are similar to those in the sedimentary deposits of the Murray-Darling Basin in southeastern Australia; Groundwater processes in the Eyre Peninsula in South Australia and the Dundas Tablelands in western Victoria are similar to those in the deeply weathered landscapes of Western Australia;

Groundwater processes on the northern and western foot slopes of the Great Dividing Range in Victoria and New South Wales show clear similarities.

The ability of a groundwater system to respond to changes depends on the capability to move groundwater which again is defined by its gradient (flow from a higher to a lower area) and the permeability of the ground (gravel, sand, clay). High gradient and high

permeability allow a faster response time (about a decade) than low permeability and gradient. In general groundwater flow systems have much slower response time to changes in land use than is widely recognized. Once those changes are initiated, it takes a long time to reach a balance. Even if a reduction in recharge is reached, it will take some time for the excess water to flow out from the system once the groundwater system is full (www.nlwra.gov.au).

3.5.4. Regions Affected by Salinity

- In Western Australia, the state most affected by salinity, 7000 farms and 1.8 million hectares are showing signs of salinity at present which could double within 20 years, and double again before a balance is established; over half the State's divertible water is already saline, brackish or of marginal quality
- In South Australia, all agricultural districts exhibit some degree of dryland salinity, and at least 20% of surface water resources are above desirable salinity limits for human consumption
- In Victoria, there are extensive impacts in western regions, which are likely to increase substantially as more detailed mapping continues
- In New South Wales and the Australian Capital Territory, as much as 7.5 million hectares could be affected in the future as groundwater rises
- In Queensland, severe salting affects 10 000 hectares, and dryland salinity is an emerging and often ignored threat, particularly in the semi-arid tropics and sub-tropical woodlands that have been subject to clearing pressure over the last 60 years. The extent of salinity in Queensland could be prevented and prevention is the most cost effective option
- In Tasmania, about 18 000 hectares, or about 2 % of cleared agricultural land is affected by salinity, and a recent analysis suggest a significant risk of more land being salinized (CSIRO, 2004).

As mentioned before salinity also poses a serious threat to Australia's fresh water supply. As it spreads, it contaminates rivers, lakes, reservoirs, and the groundwater. The potential impacts of rising stream salinity are severe. For example hundreds of thousands of people rely on the Murray River – Australia's most important freshwater resource – for their drinking water. Adelaide draws about 40% of its water supply from the Murray River in a normal year and up to 90% during a drought (Australia Water Resources Council, 1999).

The impacts of salinity are not confined to economics or agriculture. The Murray-Darling Basin and the West Australian wheat belt are already largely cleared of their original vegetation. Many of the original plant and animal species found in these regions therefore are already missing and in many cases threatened with extinction. Salinisation might deliver the final blow to many such species. According to the 2000 National Land and Water Resources Audit, the water quality of 80 wetlands across Australia is either affected or threatened by dryland salinity. In Western Australia, the Audit estimated that salinisation threatens up to 450 plant species with extinction. The salinisation of rivers, streams and lakes is also likely to cause the degradation and extinction of aquatic biota, although this has not been studied in detail (NLWRA, 2000).

3.6. Predictions

To predict areas at risk from salinity, satellite images combined with terrain maps can be used. Farm and catchment planning can be performed more efficiently if accurate information about which areas are salt-affected, where salinity is spreading or emerging, and which areas are at risk from salinity in the future is available.

Satellite images provide information about past and present vegetation cover and land condition. When this is combined with other spatial data sets that describe the terrain and the movement of water through the landscape, it is possible to predict which areas are at risk from salinity (Campbell, 2001).

At any position in the landscape, salinity risk is related to the amount of water flowing into that position, and the slope at which the water drains away. Digital elevation models show a three-dimensional view of an area and can illustrate regional drainage patterns.

The clearing of land for agriculture affects the amount of water flowing through the different regions. Information from satellite data and elevation data can be combined to show which areas have been cleared and the proportion of clearing in upslope areas (CSIRO, Land and Water, 2005).

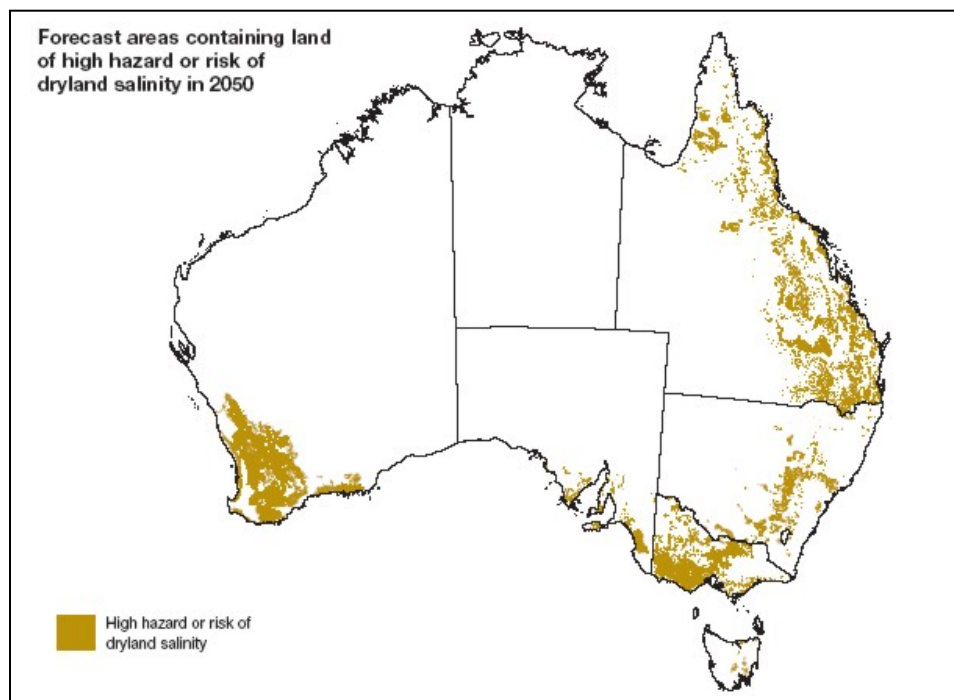


Fig.45, NLWRA, 2001

The broad distribution of areas considered as having a high salinity risk or a high salinity hazard is laid out in Fig.45. In the southern part of Australia where more precise data about groundwater levels are available more precise assessments have been possible. However, in the northern part of the continent groundwater data are rather rare or don't exist at all. In these regions, salinity assessments have been based on geological, climate and land use factors. The national map provides a basis for identifying the areas at risk where land use changes should be implemented to avoid further land and water degradation (Stirzacker, 2000).

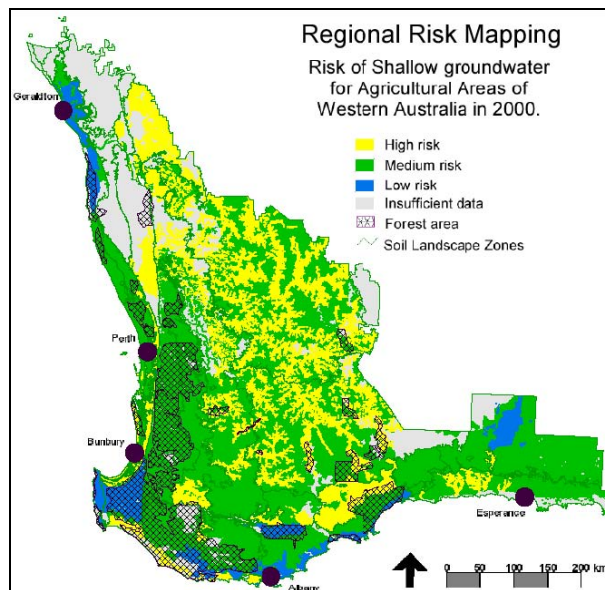


Fig.46a, Short and McConnell, 2000

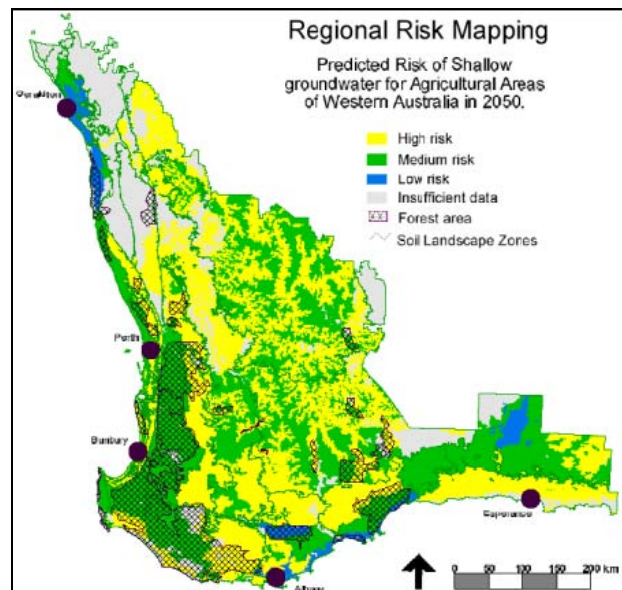


Fig.46b, Short and McConnell, 2000

In Fig. 46a the present risk of shallow groundwater for agricultural areas in the year 2000 are indicated.

Most areas at low risk are adjacent to the coast in the northern Perth Basin zone, in the southwest corner and along the southern coast (around Esperance). Areas are related to deep watertables and/or watertables with no rising trend. Most of the remaining areas of the State have been classified as having moderate risk (excluding those areas with insufficient data). There will be local variability in the extent and impacts of shallow groundwater in these regions.

Figure 46b presents the predicted risk of shallow groundwater for agricultural areas for the year 2050. In 2050 high risk has expanded in the eastern wheatbelt (north and northeast of Perth) to include all valleys and lower slopes. In these zones this will represent approximately 30% of the landscape. High risk is also apparent in the majority of zones located east of the Darling Scarp. An exception is the vegetated zone (Western Darling Range forest area) which has a moderate risk. Risk has also substantially increased in the region around Esperance on the south coast and west of Albany. Approximately 33% of the agricultural areas has potential for salinity in 2050 due to shallow watertables. Of the area at risk, 73% is occupied by agricultural land.

Summary of assets in areas at high risk from shallow watertables or with a high salinity hazard:

Asset	2000	2020	2050
Agricultural land (ha) ¹	4 650 000	6 371 000	13 660 000
Remnant and planted perennial vegetation (ha) ^{2,4}	631 000	777 000	2 020 000
Length of streams and lake perimeter 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	306	5 100
Important wetlands (number) ^{1,}	80	81	130

Fig.47, ANRA, 2000

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 Much of the remnant and perennial vegetation reported for each State occurs on agricultural lands.

3.7. Case Study: Peter and Lois Kelly Farm

Gillingarra, Shire of Moora/Central West Area, WA

Case Study: 'Lo-Bel' Farm in Gillingarra

Location: Western Australia, 150 km north of Perth, 17 km south of Moora

Property size and enterprise: 780 ha, mixed farming



Bertelsmann Weltatlas 2000

3.7.1. Physiographic Situation

The farm is situated in the Moore River catchment area in the Midlands Statistical Division of Western Australia in the mixed farming belt, between the wheat belt and the high rainfall zone. It lies on the border of two major geological regions: the Perth Basin and the Yilgarn Craton. The Darling Fault marks the boundary between these regions.

The Perth Basin is a deep trough of sedimentary rocks that may exceed 10 km in thickness. The Perth Basin sediments consist of material deposited in both terrestrial and marine environments. Quaternary sandplain covers much of the Phanerozoic sediments (Wopfner, 1997).

The Yilgarn Craton is a large area of Archaean granitic continental crust that underlies most of the southwest of WA. It is intruded by numerous dolerite dykes. Millions of years of erosion have resulted in a low relief with broad flat valleys.

The groundwater flow system in this area is local to intermediate and the depth of groundwater varies between very shallow (less than 2 m) to above 5 m. Extensive primary and secondary salinity occurs adjacent to and within the drainage lines (Jeans, 1986).

Lo-Bel lies on a hilltop of an gently undulating plateau with areas of sandplain and some laterite on granite, and slopes down to the main road connecting Bindoon and Moora; the road runs parallel to the railway line and the Moore River that empties its water into the Indian Ocean near Guilderton. The drainage runs from east to west and discharges into the Moore River. The soils consist mainly of heavy red clays, hard setting soils with acidic top-soils and alkaline sub-soils, and red loams, with a leached coarse textured topsoil profile; they are generally neutral to slightly acidic.

3.7.2. Climate Data

The climate of the Moore River catchment is Mediterranean, with cool wet winters and warm to hot dry summers. The annual rainfall across the catchment varies from around 800 mm near the mouth of the river, to around 350 mm at the headwaters. As well as rainfall variations across the catchment, the inland headwater regions are hotter in summer, cooler in winter and have less summer humidity than the lower catchment regions closer to the coast.

3.7.2.1. Rainfall (Moora)

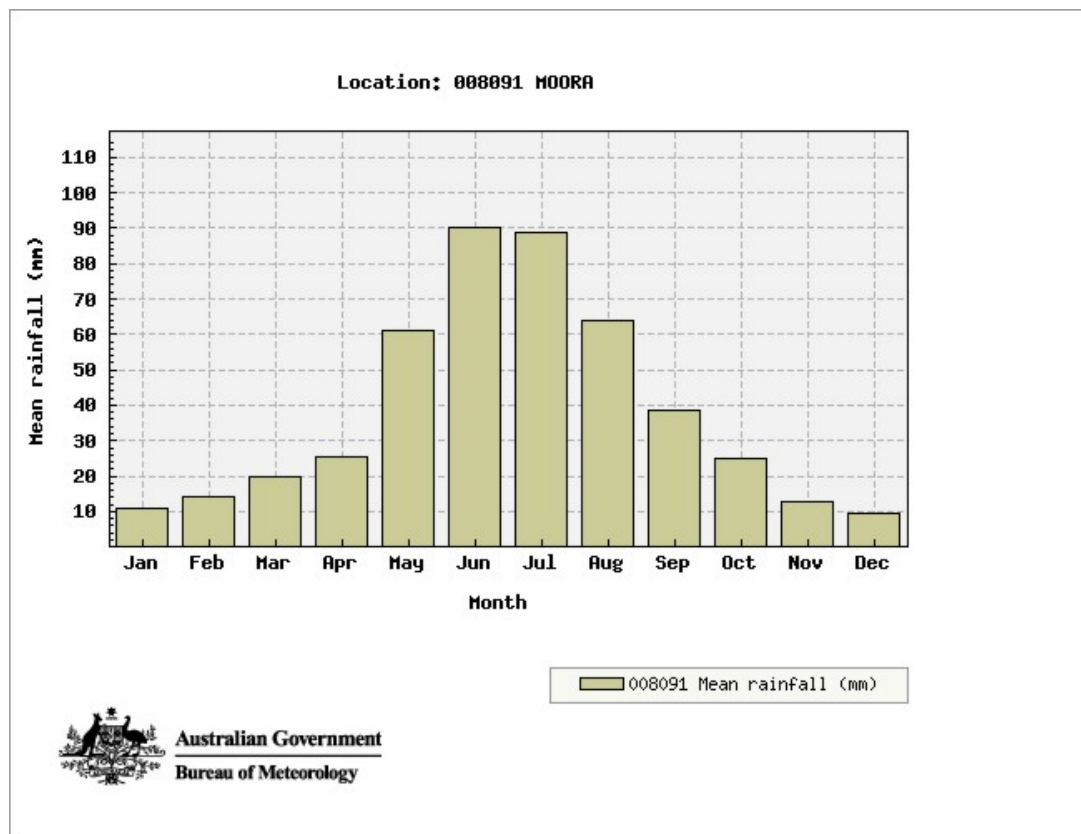


Fig.48, mean annual rainfall (1897 – 2007), www.bom.gov.au

The mean annual rainfall in the Moora region amounts to 455 mm over 60 days; the highest amounts fall during the winter season. The summer months are hot and mostly

dry even though thunderstorms occur sporadically often resulting in intense rainfall events.

Winter rainfall in this agricultural area is rather reliable in the May to October growing season, but it also can limit pasture growth in drier years and therefore the number of sheep and cattle a property can support. (In the wetter parts stocking rates of 10 sheep per hectare are common, in the drier areas this rate decreases to 2 sheep per hectare. These rates can change yearly according to the amount of precipitation).

3.7.2.2. Temperature (Moora)

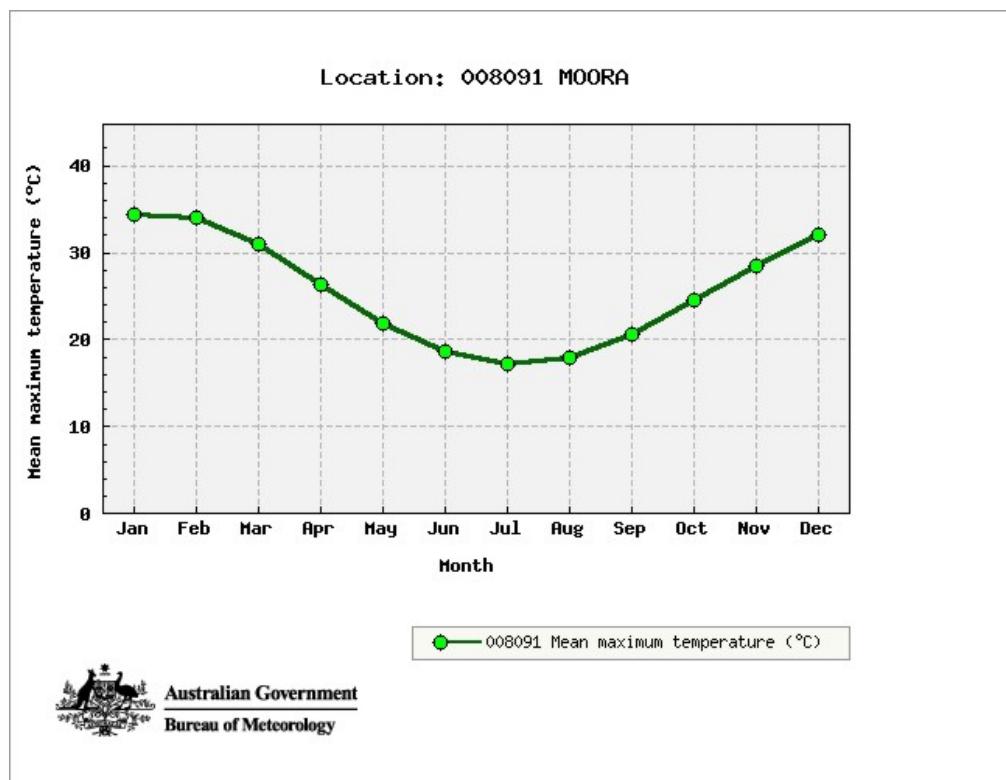


Fig.49, mean maximum temperatures (1965 – 2004), www.bom.gov.au

The maximum temperatures reach their peak in January (mid-thirties) with the lowest records in mid-winter. The average maximum lies by 26 degrees, the minimum by 12 degrees. Temperatures almost never fall below 7 degrees.

3.7.3. Background

Settlement of the Midlands took place around 1910, with large blocks of land being cleared for increased cereal production in the 1950s. From then on the development of water logging and salinity was observed along the drainage lines and lower land.

The Kelly's running a mixed farming enterprise with some crops, wheat and oats, and sheep and cattle herds. The business has been in the family since the first half of last century.

Before the first appearance of salt on the Lo-Bel farm, about 1800 farmers in the district already reported saline land the extent of which had increased by 60% in the decade to 1998.

In four short years, after the first sign of salinity in 1998, a 12 hectare patch of the Kelly property has been transformed from prime grazing country to being severely salt affected. About 40 years earlier, the adverse effects of over-clearing the native vegetation were already visible on neighbouring properties. Therefore the turnaround has been dramatic and disturbing for the family, who pride themselves on sustainable farming practices dating back to the 1960s when Mr. Kelly had decided to leave a third of the farm planted to remnant vegetation because he recognized the dangers of over-clearing.

3.7.4. The Present



Fig.51, first patches appear; photos compliments of Mr.Kelly; Fig.52, saline water seeps to surface, both 1998

An emerging salinity problem first became obvious in the paddock, which faces the main road and railway line from Perth to Moora, north of Perth, in 1998, with some salt appearing at the end of a contour bank (Fig.51 and Fig.52). This did not seem to worry the farmer too much, nothing what planting of a few trees and fencing it off could not fix. However, trees, fencing wire and posts proved no obstacle to the salt and the area continued to expand as some sub-surface moisture surfacing the following year was noticed.

In February 1999 the Kelly's had 1.5 km of shallow drains put in to deal with the excess surface water and this greatly improved pasture performance for the time being.

In the following year 5 ha of the wettest land was fenced off and 1200 trees planted with the help of school children (under a Landcare program by the Shire Land Conservation District Committee). It was a great experience for the children from the city to help looking after the environment in country areas.

But unfortunately the heavy rain and floods on the nearby Moore River in March 1999 had seemingly increased the pace of the rising water table because half of the trees got lost to salinity, and the area affected by salt had more than doubled to about 12 ha. Those trees, mainly local eucalypts, had appeared to establish well at first, but once their taproots reached the saline water table, survival was difficult. Most of the trees that had died were replanted the following year. Trees were also planted along the one kilometre strip where the main road from Mogumber to Moora meets the outer bounds of the farm. Unfortunately most of these trees fell victim to the saline groundwater as well.

During 2001 the Kelly's consulted quite a few different government bodies and neighbouring farmers, who were dealing with the same problems, to get some advice on how to tackle their salinity crisis. The 'Across the Fenceline' project by CSIRO also tried to help farmers to develop sustainable agricultural practices through a innovative mix of automated monitoring and community education.

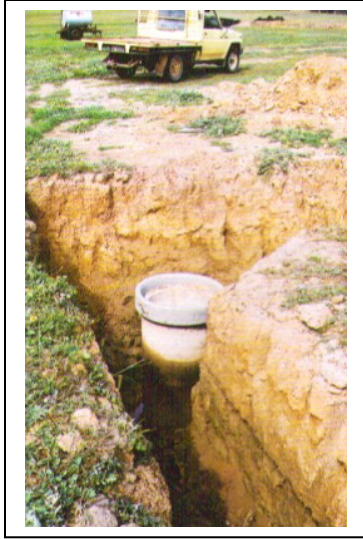


Fig.53, water table monitoring site; photos compliments of Mr. Kelly; Fig.54, pasture of perennial grasses, both 2001

One step was having 10 holes in a 300 m line put down across the paddock in December 2001 to monitor water movements and to see where the salt was coming from.

Road culvert pipes standing on their ends and surrounded by rocks were sunken about two to three metres below ground level (Fig.53) to monitor the water table. While the base of the two end pipes remained dry, water had risen to within 700 mm of the surface in others, although the surrounding pasture appeared to be in good condition.

Eight small pumps, some with solar panels, had been since installed to remove the water, their output piped into the neighbouring Moore River complying with Water and Rivers Commission requirements.

During this time the Department of Agriculture advised Mr. Kelly to plant a mixture of perennial grasses to assist in the salt control and 5 ha (especially around the edges of the worst salt scald area) were planted in November 2001 to soak up some of the moisture. Rhodes grass was the main ingredient outstripping other species and growing well in all but the most saline areas. (Fig.54, the thriving pasture of perennial grasses). Other species, including tall wheat grass, puccinellia, bambatsi panic and setaria, are slower to establish but seem to survive. Sowing the grasses was purely a trial as the farmer knew it would not solve his ever-increasing salinity problem; but he wanted to see the effects of

including them in the fight, and whether they would help in slowing down the process, especially since he had not planted perennials before.

The paddock selected for these grasses is dominated by duplex soils. (These soils have a sharp texture contrast between A and B horizon. They often have a sandy or loamy surface horizon with a sharp to clear boundary to a clay sub-soil and tend to be hard-setting in summer and waterlogging in winter; www.affa.gov.au). Here Mr. Kelly grew good clover and ryegrass before until the salt appeared on the surface; then barley grass became the main species. The area is situated in a valley floor and is moderately to highly saline.

About half of the area sown was successful; the paddock where the perennials established had about 2 cm of sand over the clay. This stopped the salt accumulating and allowed the seeds to strike. But where there were salt crystals on the surface of the clay there was no germination.

There was not much summer rain in the years prior to planting nor since planting the grasses. However, the summer of 2006 had been an exception, with the site having received more than 200 mm of rainfall.

The adviser from the Department of Agriculture suggested using raised beds or rough sowing, so there were some clods of soil where the salt had leached out so that perennials could establish all over the affected area.

The site also showed that at least some of the sub-tropical grass species had good salt tolerance; the most difficult part being the establishment of the plants.



Fig.55, Aerial view of the salt affected paddock in October 2003; photo compliments of Mr. Kelly

On Fig.55 it is clearly visible that the salt affected paddock area had expanded from the first patches of saline soil in 1998. Most of the trees planted along the Perth to Moora road (right) had died. On the far right the Moore River is visible. By 2002, the area of grasses that survived consisted of 90% Rhodes grass and 10% other grasses. Cattle first grazed the perennials autumn 2002. By 2003 there was only Rhodes grass present in the winter and by 2004, since salinity had increased, *Puccinellia* is the only species present. Overall, the perennials were not successfully established, as only half of the 8 ha sown to grasses had established in the first year (mostly in the sand-covered soil). They failed in the clayey, waterlogged soil. In addition, the salt and waterlogging problem had worsened more than the Kelly's had ever imagined, and most of the established perennials died over the following three years. So despite planting the grasses, salinity encroached at a faster rate.

Mr. Kelly realized that when dealing with salinity, the options should be multi-faceted. Even though he had no real experience with perennials prior to planting he was enthusiastic about the initial success of half of the sown area, but most disappointed when most of it died off as the area became more waterlogged and salty. Even though the salt affected area had spread over the last few years, the farmer is nowadays much more informed and aware and is determined to make it work next time. His aims are to stabilize the soil, use up the water, make the area look better, have some summer green feed and to encourage other farmers to do the same. He is even contemplating to grow some genetically modified salt resistant wheat (apparently with genes from maritime barley and rye grasses).

Despite losing 90% of the area sown with the perennial grasses, Mr. Kelly has learnt a great deal from the experience and will definitely incorporate more perennials. In 2006 he has planted 7 ha of 'Sardi 10' lucerne, 4 ha of saltbush alleys and 17 ha of perennial grasses and clover, some of it in between the alleys. The summer rain of 200 mm boosted the young lucerne stand, even though it was the farmer's first attempt to establish this legume. Mr. Kelly learnt that *Puccinellia* is the most tolerant grass of the mix he planted, whereas Rhodes grass has some salt tolerance, but unfortunately died out after the second winter.

The next option was to look at raised beds/mounding/drainage and re-sow to saltbush, Puccinellia and Tall Wheat Grass. Then a further step was to drain through the salt scald and pump excess surface water under the road and railway line. For that he needed the approval of the Moora Shire Council. Then the continuing use of saltbush and other perennials was investigated as well as the planting of more trees. The farming family desperately wanted to get the paddock back into production because of the importance of the farm to their family, and also hoping to encourage other farmers in the area to follow suit. Up until June 2004 Peter Kelly's property 'Lo-Bel' consisted of 780 ha. He has since sold off some of the land, leaving him with 200 ha. About 40% of the farm lies on the hill tops, and all areas along the natural waterways were left uncleared leaving an average corridor width of 200 m. The Kelly farm now is a mix of annual and perennial pastures mainly for sheep production.

3.7.5. Wet and Waterlogged Soils in the Southwestern Agricultural Area

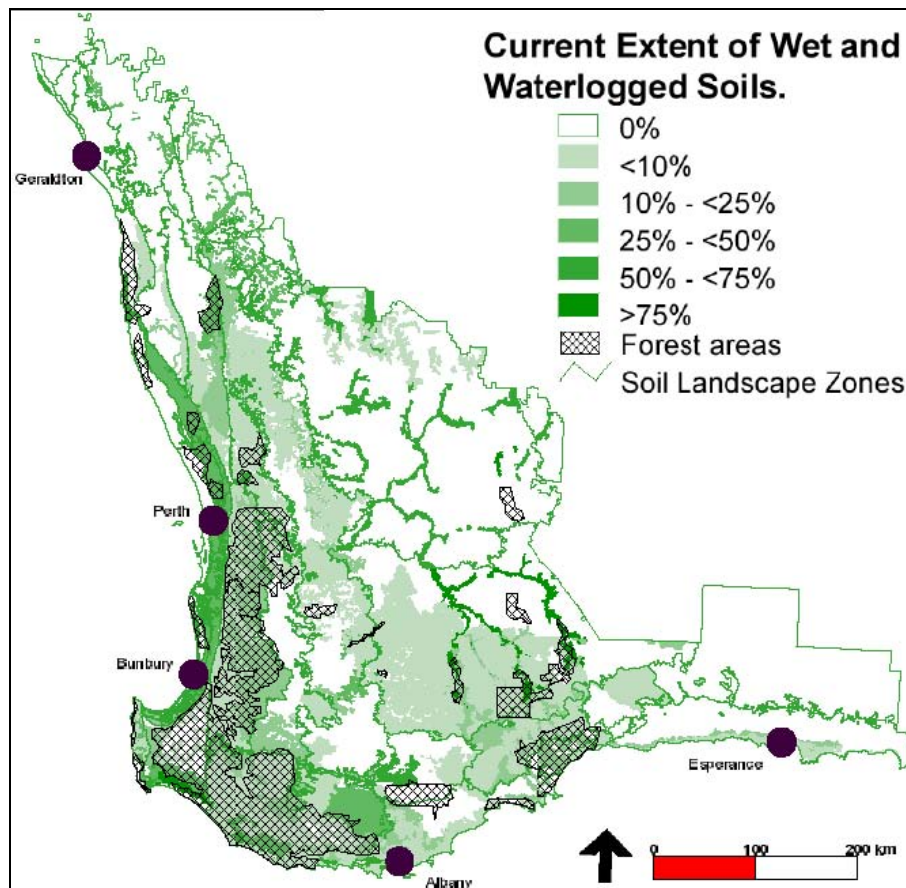


Fig.56, Short and McConnell, 2000

Fig.56 depicts the current extent of wet and waterlogged soils in the southwest of Western Australia. The map gives some indication of the proportion of the different areas at risk in 2000. However there are no estimates of the actual extent predicted for 2020 and 2050. In 2000 the risk is predominantly in the eastern wheat belt valley floors and adjacent areas. Moora district with Gillingarra lies within this region threatened by salinity through rising groundwater trends combined with high extent of wet and waterlogged soils. Eastern sections of the northern wheat belt also exhibit high risk. Rising trends in groundwater occur over most of this agricultural district.

Wet and waterlogged soils have been mapped by the National Resources Assessment Group (NRAG). The data were used to give an indication of what percentage of each district could currently be subject to salinity. The above map shows that the major drainage lines have a high component of wet and waterlogged soils (>75%) which also affects the Gillingarra farm lying next to one of these drainage lines (Moore River). The majority of wheat belt streams/rivers do not contain potable water, but there are fresh waterways in high rainfall and coastal regions. Large areas of the wheat belt currently have about 10% wet soils, and are therefore potentially saline (NRAG, 1999).

3.7.6. Recapitulation/Summing up

3.7.6.1. *The Problem*

From its beginnings in 1999, the first sighting of salt patches, the salt affected area on the 'Lo-Bel' farm has spread to 40 ha and continues to expand to the north at a rate of 150 square metres a year. By 2007 the Kelly's had spent more than A\$ 100 000 in a bid to arrest salinity and waterlogging on their farm. As Mr. Kelly admits, seven years ago they would never have guessed that the saline area would spread as it had. Over the past seven to eight years there is not much what Peter and Lois Kelly and their two daughters have not tried on the salty and waterlogged site. The farm's whole catchment area of about 750 ha is estimated to have an annual inflow of 3.9 million cubic metres, draining to the west. The salt affected site lies downhill at the bottom of the slope facing west and is bounded to the southwest by a dolerite dyke and to the west by the road and railway line, all

restricting the natural flow of water from the salty area to the Moore River, which flows just a few hundred metres away to the west.

In general the planting of trees for wind breaks and on the fringes of salt land play an important role in water use. Especially below rocky outcrops, like the dolerite dyke, the planting of trees should be taken into consideration. Where trees already exist they should be fenced off to give them a chance to regenerate. But as seen on the map Fig.56 (previous page), the whole region of the northern wheat belt/mixed farming belt is affected by rising water tables and wet and waterlogged soils especially in the valleys and along drainage lines. To combat salinity in such an area planting trees alone don't not make much difference.

3.7.6.2. The Case for Trial and Error

The Kelly's efforts, which began in 2000 with the planting of trees to reduce recharge, were followed by planting of partly subtropical perennial grasses. With an abundance of fresh water on the site, the Rhodes grass grew well as did the trees at first.

But when most of the trees started to die within one to two years Mr. Kelly realized that with a change in vegetation cover and replanting alone he could not manage the huge volumes of water feeding into the site from higher in the catchment. More desperate engineering measures – pumping and drainage – were going to be necessary.

In July 2002 Mr. Kelly got approval from the Moora Shire Council to install 1.2 km of drains that would allow the water to flow to a central point, be pumped through the road and railway line culverts and then drain through a 90 mm stormwater pipe into the adjacent Moore River.



Fig.57, one of the windmills overlooking the spreading salt patch. Fig 58, saltbush on mounds struggle to survive; photos taken by the author, 2007

Over time, Mr. Kelly installed six windmills to pump the drain water up into a tank, which would then gravity feed into a main drain under the road and into the river. So far he has pumped an almost unbelievable amount of 26 000 gallons (1 gallon = 4,5 l) daily since July 2002. Since then, the quality of the drainwater has improved from 570mS/m in July 2002 to 190mS/m today. Without the installation of the drains and pumps, the salt affected paddock would have become a total wasteland. Drainage was like pulling the plug – it allowed the area to flush.

The drains were 2 m deep and open, but Mr. Kelly has laid 15 cm diameter pipe in them and filled them in because they were silting up. He has even tried used tyres as buried drains to keep the sand away but this was extremely labour intensive. The next option was the 15 cm pipe, but it was difficult to keep the pipe flat and in some parts it silted up so it had to be repeatedly flushed out. If the farmer would start again from the beginning he would put the pipe into the freshly dug drain and cut slots into it every 20 m and place rocks over the slots to allow filtered inflow.

Part of the Kelly family's effort to curb the salt affected area has also included their involvement in the Sustainable Grazing on Saline Lands project, supported by the government. Originally, the project covered 15 ha, but Mr. Kelly has worked on a much broader area.

Luckily the family got a lot of technical support from this project (SGSL). There are more than a dozen SGSL projects across the agricultural region and the program encourages farmers to look at how producers in other areas are dealing with salt affected pastures. Also the Catchment Demonstration Initiative (CDI) more recently was of great help. The CDI (Department of Agriculture) aims to demonstrate combinations of various salinity management practices to recover saline land.

The Kelly family's efforts to revegetate the site and surrounding area had been relentless and ongoing. The perennial grasses were followed by plantings of saltbush seedlings and 5000 salt-tolerant eucalyptus trees. Mr. Kelly said trying to establish vegetation had been hit and miss most of the time. He planted 4000 saltbush seedlings in July 2006 but only about 300 survived because of the dry season.

In a bid to slow some of the recharge northeast of the site, in 2006 a 10 ha area was sown with lucerne which afterwards was rotationally grazed. The lucerne, being a deep-rooted plant, proved to be an outstanding success so far. Some salt-tolerant couch was also planted.

3.7.6.3. Site Improvement

The site has changed much in the seven years of treatment. Areas that originally were bare and scalded now support saltbush plants 1 m high, partly planted in mounds. This saltbush helps to reduce recharge and waterlogging and can be used as a fodder plant. Tall wheatgrass and some other hardy perennials are growing in parts which are less saline. Deep-rooted salt-resistant lucerne were planted as pasture for grazing animals and to use up some of the excessive water. On the clayey/loamy soils of the site Mr. Kelly is using minimum tillage when sowing crops to avoid further deterioration of the surface. Unfortunately on the other hand, salt-tolerant eucalyptus planted on what were the northern fringes of the original salt-affected area are dying and other pasture areas are lost to salt scald.

But the Kelly family is not giving up their fight. They probably will have to install a further 500 m of drain to keep on top of the waterlogging. Mr. Kelly is also looking at contour and grade banks to reduce runoff and waterlogging but this still needs more detailed surveying and construction. Ultimately the aim is to reclaim 75% of the site with vegetation that can be grazed by livestock.

As can be seen, some simple engineering solutions to overcome the problem of soil degradation and salinity don't exist. The practical reality is that planned land use, careful management of crops, pastures and livestock and the use of native trees/grasses will be more successful in the long term.



Fig.59, satellite image by Google Earth, 2008

The satellite picture of 2008 shows the extensive work the Kelly's have done on the site: planting trees, sowing lucerne, putting in herringbone pattern of sub-surface drainage (only partly visible); trying to establish saltbush in mounds leading into the defined drainage areas, and sowing some more tall wheatgrass and puccinellia. But despite all their efforts the saline area has expanded further, stretching even across the road and railway line towards the Moore River.

4. Managing Dryland Salinity

4.1. Land Management Recommendations

Salinity problems are often caused by and reflected in the reduced number of trees across the landscape. One immediate management option involves restrictions on clearing, promotion of revegetation, particularly at critical sites in the landscape. Long term solutions, however, need to tackle the problem at its source through appropriate changes to land management. Engineering solutions to the salinity problem, such as salt interception schemes, may provide interim relief, but generally only deal with the symptoms (Department of Agriculture, 1997).

Excessive use of groundwater resources which can lead to saltwater intrusion into aquifers, especially in coastal regions, raise a different set of issues. Management options include water pricing and extraction policies and artificial recharge schemes.

In developing plans to meet community objectives, agricultural managers will need to consider all sources contributing to salinity within a catchment, including dryland agriculture, irrigation areas, sewage works and intensive rural industries. Appropriate policies for each of these sources will need to be developed (www.csiro.au).

Many vegetation and pasture management practices can lead to improved productivity while reducing the groundwater accessions that are common to both dryland and irrigation agriculture. In the case of irrigation, these farming practices may be supplemented by activities aimed at reducing water usage. Improved irrigation technology, laser grading, improved water ordering and water recycling all contribute to water conservation. Improved management practices will ensure reduction in salinity of local and regional waterways and ease the threat of widespread land salinisation.

Salt in irrigation drainage water and rural industries' waste could also be addressed through regulatory or market-based measures that impact on discharges, such as drainage charges. The establishment of markets for water entitlements is seen as an essential mechanism for enabling reallocation of water areas prone to salinity (www.affa.gov.au).

Community participation is an essential element in the management of salinity. Many Landcare and catchment management groups already target salinity. Their activities form a sound base for wider community involvement. To involve the community in tackling salinity problems, it is important to improve understanding of the specific salinity processes involved, their impact and effects. To equip individuals, groups, industries and organizations with the knowledge, attitudes and commitment to take an active part in its management and control, a package of education programs should be developed (Australian Water Resources Council, 1998).

The range and measures the Australian Government is applying to the salinity problem includes research and development, making direct on-ground interventions, and developing timely information on salinity and expansion capacity. In collaboration with the states and territories, the Australian Government is dealing with salinity through a wide range of initiatives and research development bodies.

4.2. Current Situation

Years ago the salt problem was just another topic for scientific meetings and loss of biodiversity was regarded as a nature conservation issue. Today it is front-page news and not only in Australia; it is a worldwide problem. Ecologists have documented the decline and loss of biodiversity and the change in ecosystem processes and are concerned that salinity and loss of biodiversity are often treated as completely separate issues. They are not, as salinity is an extremely visual manifestation of the loss of major elements of biodiversity and change in ecosystem processes (Soil and Land Conservation, 1995).

Agriculture has flourished over much of the world for thousands of years, beside the changes brought on by ploughing virgin land. In Australia, already at the end of the 19th century observers were making the connection between land clearing and salinisation, although the underlying processes were somewhat misunderstood. A detailed description of the problem pointing out the fundamental issues was already published in the early 1920s (www.agric.wa.gov.au; www.daff.gov.au).

Nevertheless agriculture continued to expand and became the foundation of a prosperous economy. At the same time more water has been leaking below annual crops than the

aquifers can deliver to rivers. As aquifers fill and watertables rise, the deep and ancient stores of salt are lifted to the soil surface, killing much of the remaining native vegetation and its associated fauna, while the salt is carried to the rivers (www.abs.gov.au).

4.2.1. Background

In general the belief is that Australian farmers imposed a European agriculture completely unsuited to Australian soil and climate which is true but not really fair. For all human societies that have forsaken a hunter-gatherer existence have based their civilizations on annual seed-bearing plants such as wheat, rice and maize. It is the replacement of native perennials with annual plants that caused the upheaval in land management (ABS, 2002).

Annual plants match their life cycle perfectly with the favourable growing seasons and they overcome the harsh times as seeds. This made the annual plants perfect for domestication because its large seeds favour the survival of the next generation. For example, the wheat plant stores half its total biomass as starch and 70% of its nitrogen as protein in its seed. Perennial plants cannot match this at all. Their strategy is to survive the hard times. They need deep roots to tap the last drop of water and sometimes woody stems to be able to outgrow their annual competitors (www.agric.wa.gov.au).

Annual plants are more suited to intensive agriculture. Ploughing and herbicides remove competitors and allow a perfect match between the seasons and the plant's requirements. The productivity of the annual and its apparent wastefulness are linked. Typically 5-15% of the long-term average rainfall gets past the roots of the annual plants, whereas less than 1% escapes the native perennial vegetation (Barnett, 2000).

The removal of vast areas of native vegetation (in some cases up to 95% of areal extent) has resulted in 5-15% rainfall leakage past the root zone in agricultural land. This has caused the changes in land and river salinity and the widespread loss of biodiversity, and changes to ecosystem processes. If there should be any impact on these processes new perennial species will have to be introduced into agricultural landscapes which will be a difficult task, given that perennials are less beneficial to intensive agriculture (CSIRO, 2007).

4.2.2. Conclusion

- Current farming systems are the fundamental cause of the dryland salinity problem
- Under best management practice, the leakage from most agricultural land still far exceeds the capacity of the landscape to shed the excess water
- For most of the country there are no profitable systems to replace existing land use
- Even if completely different farming systems would be introduced immediately, it will be a long time before an improvement in salt trends will be noticed (National Land and Water Resources Audit, 2000; CSIRO, 2002)

4.3. Setting Targets

4.3.1. Imitating Native Vegetation

A first requirement is to try to reach the leakage rates of the original vegetation, a condition to avoid or reverse salinisation. The target is to retain a productive landscape by imitating the hydrological function of native vegetation with economically viable species. It is not possible to reverse the salt trend to the state that existed before clearing due to the vast quantities of salt already mobilized by rising water tables. But the spread of salinity can be limited by creating a productive agricultural landscape that mimics the water use pattern of the original bush. However without profitable tree crops, especially in low rainfall areas, the only way to do this is to revert to native vegetation with serious implications for agriculture and rural communities. Still, native vegetation and re-vegetation has a most important role in salinity control. Upkeep of remnant native vegetation to conserve and maintain biodiversity and ecosystems is a main target (Australian Conservation Foundation, 2005).

4.3.2. Land Protection

A second target is to ensure that recharge levels remain less than the discharge capacity of a catchment. The discharge capacity is the amount of water that the groundwater aquifers can carry – water that eventually will be delivered to a stream. As long as the recharge rate is less than the discharge capacity, watertables will not rise to the surface and land and infrastructure will not be lost to salinity (www.csiro.au).

This target is made difficult by the complexity of measuring leakage and discharge capacity with reasonable accuracy. Also has to be considered that there are time lags within the systems. In many areas, salt discharge will continue to rise even after recharge has been reduced. In local groundwater systems the salt discharge may rise for a decade or more. In larger regional systems the rise could extend to hundreds of years no matter what steps are being taken (ABS, 2004).

4.3.2.1. Soil Conservation Measures as Part of Land Protection

Working with contour banks or graded banks in hilly cropping districts will aid in reducing soil loss. Contour banks are earthen structures constructed across cultivated slopes, at intervals down the slope. They intercept runoff and channel it into waterways, natural depressions or dams. Their function is to reduce slope length and to intercept runoff before it concentrates into an erosive force. They also trap much of the sediment from overland flows and drain excessive water from the paddocks which reduces the threat of waterlogging (National Land and Water Resources Audit, 2000; Lenane, 1990).

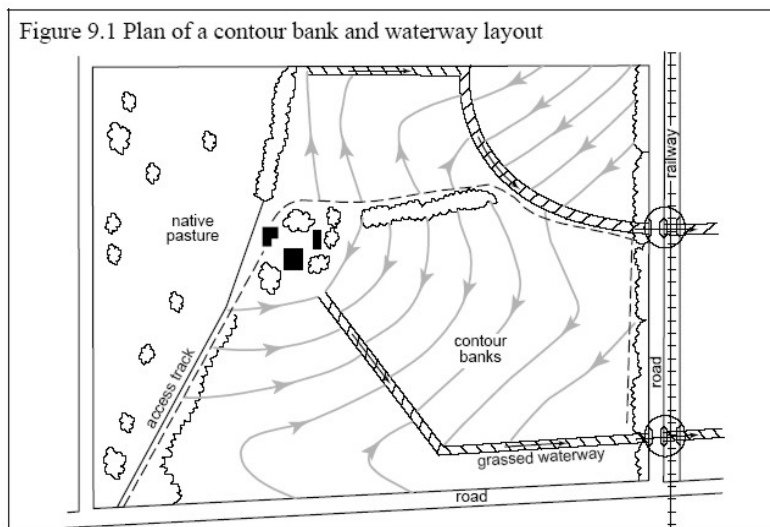


Fig.60, www.nrw.qld.gov.au

Contour bank layouts (Fig.60) require careful planning to ensure the satisfactory coordination of runoff within a catchment and between properties. The idea of raised bed farming to reduce the effects of waterlogging and salinity came from irrigated agriculture and has been adapted to dryland. Studies indicate that soils need at least 8% of air-filled

pore space for plants to avoid waterlogging stress. In raised beds topsoil is piled about 20 cm above the normal surface leaving furrows, which act as drains between rows. Soil in the beds is better drained and less compacted, improving plant growth and crop yields. Spacing between furrows is determined by practical consideration such as tractor span. Furrows also provide access to the paddock without damaging the crop. (Special bed-formers cost about \$ 40,000, but the costs should be made up for within a few years through higher yields) (National Land and Water Resources Audit, 2001).

4.3.3. Protection of Water Bodies

A third target is to keep the salinity of streams below a certain threshold, about 800 EC, which is the Australian limit for desirable drinking water.

4.3.4. Current Option

There is no single land-use system to combat land degradation and salinity. More research is essential into options and possibilities to maintain and restore some of the health of the landscape and its biodiversity (CSIRO, 2004).

4.4. Monitoring the Extent and Spread of Salinity

In the past, farmers estimated the extent of salinisation on their properties in response to questionnaires issued by the Australian Bureau of Statistics. This method is thought to have underestimated the extent of salinisation, partly because the recognition of this problem varies between farmers. Such methods don't provide maps of where the salinity is and where it is spreading to with which rate.

4.4.1. Remote Sensing

The newer techniques developed involve remote sensing – collecting of data from devices fitted to aeroplanes or satellites (CSIRO, 2004).

Airborne geophysics has now been enlisted in the fight against salinity. This technology, already being used by mining industries for decades to help locate ore beneath Australia's surface, now adds to the land manager's "arsenal", providing a new layer of information

about the makeup of the underground structures that impede or enhance the movement of salt and water.

With salinity costing upwards of \$ 500 million a year in environmental and agricultural degradation, the Federal Government has invested heavily in making airborne geophysics data available to support natural resource planning and salinity management (CSIRO, 2006).

Airborne geophysics technologies consist of:

- *Airborne electromagnetics (AEM) transmits currents as it interacts with different materials on the ground*
- *Radiometrics reveals the geochemistry of surface cover through gamma radiation and can detect potential salt stores*
- *Magnetics probes underground geological structures such as faults, rock bars and buried ancient stream channel*
- *Altimetry generates a digital elevation model of the morphology*
(CSIRO, 2006)

4.4.2. Electrical Conductivity

Another airborne electromagnetic technique makes use of the fact that electrical conductivity increases with increasing salinity. It involves an aeroplane flying low over the ground with an electromagnetic transmitter on board. Trailing behind on a cable is a receiver that records the electric currents in conductive areas. The analysis of the recording determines the conductivity of the ground (CSIRO, 2006).

4.4.3. Landsat

Increasingly, scientists use satellite images to recognize salinity patterns. Most of these images are supplied by a series of scientific satellites – Landsat. They orbit the earth recording information about electromagnetic radiation reflected by the earth's surface. Satellite images provide information about past and present vegetation cover and land conditions. When this is combined with other spatial data sets which describe the terrain and the movement of water through the landscape, it is possible to predict which areas are at risk from salinity (CSIRO, 2006).

5. Projects

Federal and State Governments and other official bodies and institutions involved in research, management and designing tools to tackle salinity, have set up various projects and programs to deal with and to combat the ever increasing problem of salinity.

5.1. Redesigning Agriculture for Australian Landscapes (RAAL) Research and Development Program

This project is a joint initiative of the Land and Water Research and Development Corporation and CSIRO. The program is researching how agricultural systems in Australia can be redesigned to address a range of sustainable issues. Its objectives are:

5.1.1. Objectives

- To understand, by comparison, the key biophysical processes affecting leakage of water and nutrients in cropping, grazing, and natural systems
- To benchmark criteria for redesigning agricultural systems in Australian landscape
- To develop a toolbox of redesign options to modify current, or develop new, agricultural systems for Australia
- To facilitate implementation of redesign options in priority Australian landscapes by exploring the socio-economic policy, the marketing and technological requirements and implications of each option (www.lwa.gov.au)

5.1.1.1. The Design Approach has Potential to be applied through:

- Selection and plant breeding – including molecular genetics – for commercial crops, pastures and native plants to manipulate phenology, canopy development, rooting function, distribution and temperature response
- Rotating and mixing, in space and time, innovative configurations of plants, including: annual and perennial crops, pastures, forest and horticultural trees, native plants and bush foods, in alleys, blocks, windbreaks and clusters, over rotations of months or years (National Land and Water Resources Audit, 2001).

Recognizing the diverse skills and inputs necessary to achieve its mission and objectives, the RAAL Program will actively seek opportunities to collaborate and incorporate outputs into other research and development initiatives.

5.1.2. Options and Future Prospects

(CSIRO, 2007; Dept. of Environment, 2008; RAAL, 2005)

5.1.2.1. Opportunity Cropping

One option to increase water use by annual cropping systems is to sow crops opportunistically in both winter and summer, when rain and soil water conditions allow. This makes a useful contribution in areas with significant summer rainfall. Opportunity cropping is a relatively new area in research agronomy. An applied research effort over the next 5-10 years on suitable crop/soil/rainfall combinations could yield improved systems in terms of salinity control and profitability (CSIRO, 2007).

5.1.2.2. Phase Farming

This kind of farming involves growing woodlots (blocks of tree plantings) in rotation with crops or pasture. The woodlots can ‘mine’ soil water that has built up during the agricultural phase. Deeper profiles with heavy textured sub-soils offer the best prospects. A typical rotation might be three to five years of enhanced growth. Here the focus lies on the role the woodlots play in controlling the local hydrological balance through recharge control. Mostly phase farming systems only use a series of crops alternating with a few years of perennial species. It is one of the most promising innovations for controlling recharge in cropping areas (CSIRO, 2007; Stirzacker, 2000).

The system exploits the storage capacity of the deep subsoil, allowing it to fill during the cropping years, and emptying it under the perennials. Lucerne has most potential of commercial species to fit in with ley-farming enterprises for it can prevent leakage most of the years, and also protect subsequent cropping in a rotation. The introduction of a perennial deep-rooted pasture phase that can dry the soil to 3 m depth into a cropping rotation (three years pasture followed by three years wheat) drops leakage by 70% or more (Australian Water Resource Council, 2004).

5.1.2.3. *Companion Farming*

Companion farming is an emerging concept in which annual cereals are oversown into a perennial pasture system, ideally one that exhibits a strong degree of winter and spring dormancy. The perennial pasture may be native grasslands or deep-rooted legumes such as lucerne or other novel species. Oversowing annuals into winter dormant perennial pastures may be a way of getting around the issue of year to year variability in leakage and the technical difficulty of changing phase.

These systems appear to be potentially more effective than phase farming in controlling leakage, with at least the same grain yield production possibilities. However, there may be a trade-off in production through competition for water and problems with obtaining a clean harvest (www.lwa.gov.au).

More research is needed in this area to finally provide viable systems.

5.1.2.4. *New Agricultural Plants*

The current crop and forage species have been bred and/or selected for yield and desirable agronomic characters. Little or no attention has been given to their ability to use water and nitrogen and restrict dryland salinity (www.agric.wa.gov.au).

Some potential exists to select or breed long season deep rooted cultivar or perennials of current crop and fodder plants with high leaf area that may substantially reduce deep drainage, and to fit these plants into new farming systems. Good prospects exist to

develop winter wheat with canola varieties that can be sown as early as February, if rainfall conditions allow, and grazed in May. They then regrow to produce a grain yield over the normal spring-early summer period (www.nlwra.gov.au).

Of all the conventional crops, none has a higher water use than canola, depending on varieties. Certain breeds of barley with a longer growing period are also taken into consideration. Another crop enlisted in the Salinity Action Plan is the high protein legume, tagasaste (or tree lucerne) which successfully is mimicking the water use of native vegetation. On saltland not affected by waterlogging and flooding, saltbush and bluebush will grow as well. But it would be unwise to attempt to grow bluebush and saltbush on land that is bare and subject to waterlogging and severe salinity (www.asris.csiro.au).

Long term opportunities lie in the use of both improvements in conventional plants and developments in biotechnology to develop new plants with more extensive root systems, greater perenniality, and different degrees of winter and summer activity. Other components like enhanced early vigour, waterlogging tolerance and disease resistance would also improve their use of water.

It may even be possible to add ‘resurrection genes’ to annual crops, giving them the ability to re-sprout after harvest in the event of summer rain. At the extreme, it might even be possible to produce perennial grain crops, although it is highly likely that there will be a trade-off between productivity and persistence.

Most of these developments will require quite a few more years of research (CSIRO, Land and Water, 2004).

5.1.2.5. Organic Farming

Organic farming is increasing in importance due to rapidly growing market preference. Organic farming uses crop rotations and diversity to replace agrochemicals, but this does not necessarily mean a shift to greater use of perennial plants. A similar reliance on annual species will expose organic farming to the same risks of leakage as conventional agriculture. Research to give greater emphasis to deep-rooted perennials in phase planting or as companion plants is attractive because organic farmers are skilled and know from

their own experiences about the complexities of crop/pasture/tree management (www.anra.gov.au).

5.1.2.6. Tree Products

Research has shown that planting trees over shallow water tables is a practical way to reduce saline discharges in locations where the water is not too salty and lateral water movement prevents salt building up in the soil. However, in the much more common situations where aquifer systems are large and saline, salt accumulation will make such plantings unsustainable. Choosing species suited to the particular climate and site conditions and appropriate management practices are essential to realizing the potential benefits of tree planting for salinity control (State Salinity Council, 2000; Heaney, 2000).

5.1.2.6.1. Trees should be planted for the Following Purposes (www.nlwra.gov.au)

5.1.2.6.1.1. Trees for Windbreaks

Strong winds can cause problems almost all year round

- Soil erosion occurs on soils that have been heavily grazed
- Sand blasting of young crops sometimes occurs to the extent that large areas may need to be reseeded
- Hot dry winds at flowering times will reduce yield
- Cold winds and rain cause losses among lambs and freshly shorn sheep
- Trees planting for dust abatement around mining and industrial towns in arid areas, demonstrates that dedicated effort can improve a windy environment

5.1.2.6.1.2. Trees to dry up Seepage Areas

Certain types of trees can be used with or without drainage to dry up seepage and prevent the development of salinity

5.1.2.6.1.3. Trees to stabilize Wind-blown Areas

Where there are problems stabilizing the soil with the retention of stubble, and particularly where crop yields are marginal, trees should be used to stabilize the soil

5.1.2.6.1.4. Trees around the Fringes of Saltland

Trees on the fringes of saltland will dry the surface out and prevent further spreading of salt. The fencing of these areas will encourage revegetation that in turn will protect the soil surface. Trees are capable to lower the watertable quite considerably and salt tolerant trees can also reduce groundwater salinity (WA Dept. of Agriculture, 1988).

5.1.2.6.2. Tree Planting and Management

On well drained land, trees will need to be planted as soon after the first general rains as possible, this will give them a chance to develop a root system before the summer.

On saline or waterlogged soils it is necessary to wait until the spring when the possibility of flooding and severe waterlogging has passed. Wherever livestock is kept trees must be securely fenced until they are large enough to survive. Temporary or electric fencing can be used to reduce costs. With tree planting, weed and vermin control is necessary, protection from fire is also important.

A wide range of native trees can be planted according to the individual conditions of the areas; these include: various species of wattle, paper bark and tea trees, sheoaks and a big variety of eucalypts (Pannell, 2001).

When the surface is dried out there will be less evaporation and the deposition of salt will be reduced. Trees and grasses will use the surface moisture and also will protect the surface from the effects of wind and water erosion. Wind and water erosions are important processes in the development of saline areas and must be controlled for the successful reclaiming of saltland.

Trees to be planted nearest the salt land should be: (www.brs.gov.au, www.csiro.au)

Western Australian swamp sheoak (*Casuarina obesa*) and Kondinin blackbutt (*Eucalyptus kondininensis*). A general rule is to plant these trees on the barley grass usually adjoining the bare saltland. Next to them salt-river gums (*Eucalyptus sargentii*) should be planted, combined with river red gum, white gum and shrubs such as bottlebrushes, paper bark and wattles.

Eucalypts are well adapted to the Australian environment. At most sites where tree water-use has been measured, eucalypts showed themselves capable of using at least as much as the annual rainfall (www.science.org.au).

While tree planting/reforestation is possibly the most effective land use option for managing saline leakage, it is not yet enough viable commercially due to a lack of markets to drive revegetation at the necessary scale. A well focused research effort over the next 25-30 years will be essential for the development of: new markets; bush foods; tree crops to produce fruits, nuts, oil, pharmaceuticals; forestry products including specialty timbers, charcoal, carbon credits and biomass energy applications (www.environment.gov.au; Heaney, 2000).

5.1.2.6.3. High Rainfall Tree Products

Forestry for pulpwood (paper) and logs for sawmills is a potentially valuable land use where annual rainfall exceeds 800 mm. Where rainfall is below this limit, forestry is more difficult. While planting trees would probably improve water quality, the volume of run-off would certainly decline due to increased evapotranspiration by the trees. So eventually the value of the water may be greater than the value of the timber. This area of research is critical to managing afforestation. Also in medium-high rainfall areas planting of new trees will affect the magnitude and distribution of flows over time and reduce the incidence and severity of flooding (Ive, 2000; Loveday, 1993).

Even though these trees (pines, some types of eucalypts) are effective in reducing leakage, more research is needed to extend profitable forestry to large areas.

5.1.2.6.4. Low Rainfall Tree Products

As the growth rate of trees decline with rainfall, their commercial viability depends increasingly on high value/low volume products like essential oils and tannin from native wattle and pine. Another emerging industry makes use of Australian native species to produce food. So far the main native food harvests came from the wild but there are increasing efforts to cultivate these plants – quandong, acacia (for wattle seeds), native citrus, mountain pepper, riberry (clove lillipilly) and lemon aspen. The list includes some arid zone species and others from higher rainfall areas; most of these species are relatively widespread in the native flora (State Salinity Council of WA, 2000).

Another important tree crop for the future may well be the production of ethanol or methanol as replacement for fossil fuels. Models have suggested that 30 million hectares of trees and shrubs would be required for Australia to make the transition to an ethanol-fuel based transport system. It would provide a large amount of jobs and reduce greatly carbon dioxide emission. So far the cost of producing ethanol still outweighs the current transport fuel expenses but government policies may make such land uses economically feasible in the not too distant future. In addition, the federal government of Australia has a taskforce currently exploring options for increasing the renewable energy component of Australia's transport fuels (www.anra.gov.au; www.csiro.au).

As explained above, different tree specimen can be grown as well in high as in low rainfall areas. To introduce trees into agriculture at the least cost for the landholder, poorly performing cropped areas should be identified and set aside. Hill slopes exceeding 3-5% tend to contain wet areas that are prone to waterlogging, salinisation and erosion. Those are ideal locations for tree planting. Revegetation with perennial plants would not only reduce recharge but also provided opportunity for creation of habitat for the maintenance of native biodiversity (Malcolm, 1972; www.csiro.au).

Another way to deploy trees tactically is to plant them over areas with particularly large salt stores so that this salt is not mobilized. New techniques are being developed to identify such areas.

Over recent years there has been a greater awareness of the values of trees in the landscape as mentioned before. Most farms would benefit from the planting of trees. But in some areas, like the dry wheatbelt, the limited number of reliable species grown by nurseries has made the selection of trees difficult (Pannell, 2001).

Native trees are valuable, provided they are planted in their correct environment, for rising watertables and salinisation have killed many indigenous species in the past decades (National Land and Water Resources Audit).

Tree planting in low-lying areas is not successful most of the time, as the soil there is prone to waterlogging. Farmers are urged not to accept seedlings unless they meet the criteria required for successful planting.

5.1.2.7. Agroforestry

Agroforestry can be more profitable than tree crops alone, but its effectiveness depends on the proportion of trees planted, and on the skill of putting them in the right parts within the landscape. Trees spread across a catchment belt are likely to grow faster and have a bigger impact in reducing groundwater recharge than the same number of trees in a woodlot. The drawback, however, is that crop and pasture may be reduced over substantial areas because of competition from the trees for water, nutrients and light. Since the value of trees is less than that of crop it makes agroforestry not really economic (www.anra.gov.au; www.affa.gov.au).

Edge rows of tree belts have shown enhanced growth but also need more attention and therefore are less profitable than cropping. The aim of agroforestry is for the trees to use water that would have contributed to leakage, not water that would have been used by the crop. This balancing act is difficult to achieve especially in a variable climate.

Mixing trees and crops introduces the problem of competing for light, water and nutrients. Tree/crop combinations will only be profitable if the value of tree products and any benefits from shelter (windbreak) exceed the value of displaced crops and decline in yield through competition (www.anra.gov.au).

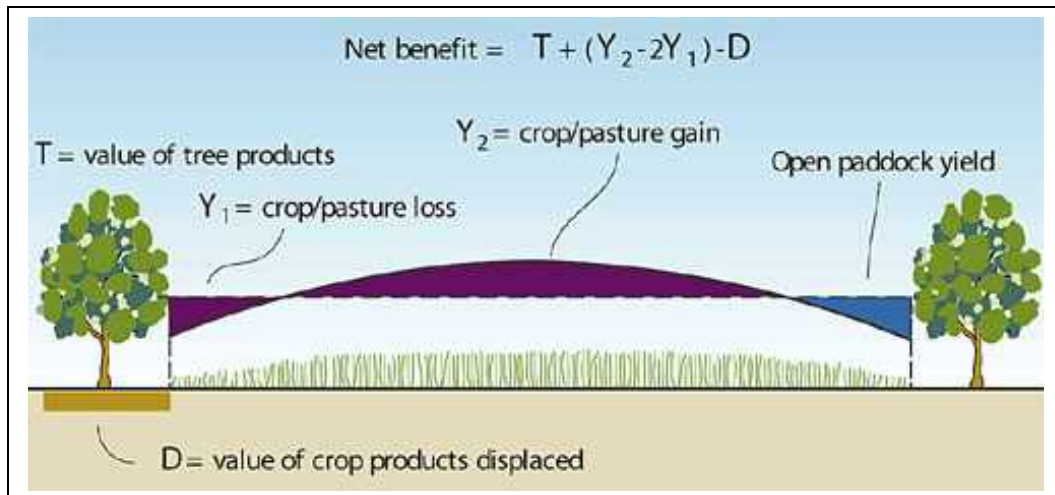


Fig.61, model of a tree/crop combination, www.anra.gov.au

The net benefit of tree belts (Fig.61) is a combination of the value of the tree product plus yield enhancement due to shelter less the areas of land displacement and the crop lost to competition

Further research is needed to determine which tree/crop/pasture mixtures can reduce leakage to acceptable levels and continue to give economic return.

5.1.2.8. Perennial Pastures

Perennial grass pastures are capable of using higher rates of water than trees in the short term (days), but cannot match the performance of trees over the medium and long term. The reason being that perennial grasses seldom have roots stretching below 2 m, where tree roots frequently reach below 6 m.

Lucerne has proved to be a herbaceous perennial in a class of its own, frequently drying the soil profile to 3 m and more, and is of special interest in phase farming.

Even though perennial pastures leak less water beneath the root zone than annuals, but higher rainfall, winter dominance, acid and shallow soils, and grazing pressure all compromise their potential. Research will have to focus on more resistant and deeper rooting species (Pannell, 2001).

5.1.2.9. Saltland Farming (www.farmingahead.com.au)

Salt makes water less available to plants so that they experience the stress of drought in a wet soil and their growth rate is reduced. When salt gets into a plant it causes progressive leaf fall and ultimately death. However, some plants and trees can exclude most of the salt at the root surface and tolerate a high concentration of salt in their leaves.

Salt tolerant plants using only small amounts of groundwater can have a large effect on the watertable. Even if plants use only 0,1 mm/day of groundwater over a year, the watertable would drop 30 – 60 cm. But unfortunately the salt becomes concentrated in the soil above saline groundwater. Since plants use essentially fresh water, the excluded salt is left behind in the soil. The freshwater transpired is continuously replaced by salty groundwater. Even if the groundwater starts off slightly saline, the concentration of the salt in the root zone will approach that of seawater, thus precluding further uptake.

Planting discharge areas with salt tolerant vegetation remains an important strategy for reducing the risk of spreading localized salinity, reducing the visual impact of salted land, reducing soil erosion and maybe salt transport to waterways, and obtaining some productivity from salt tolerant grasses and shrubs. Small groundwater systems might respond to such treatment but above larger groundwater systems salt will continue to accumulate (www.csiro.au; www.crcsalinity.com).

Once the salt concentration exceeds the threshold of the tree to take up water, the very process that brought the watertable within range of the tree roots will continue to operate and drown the trees in low lying discharge areas, unless the salt can be removed. Planting trees in discharge areas are hardly ever a substitute for plantings in recharge areas.

Saltland farming does allow for some soil stabilization and provision of stock feed but make little long term contribution to managing the watertable, reducing salt loads to rivers and therefore to water quality. Identifying species and management practices that make best use of such land is important because of the huge areas that will be affected by salt, but the impact of this research on controlling land and river salinisation will be relatively small (futurefarmcrc.com.au, www.affa.gov.au).

In future the Australian scenery might look rather different. A new landscape should emerge, made up of a mosaic of commercial tree crops, mixed perennial-annual cropping systems and areas of native vegetation. As well as controlling the effects of salinity these future landscapes will help to protect Australia's biodiversity. But before this vision can be realized, much more research is needed to develop suitable plant varieties and cultivate markets for their products (www.napswq.gov.au).

5.2. National Dryland Salinity Program

The **National Dryland Salinity Program** (NDSP) was the major focus of Australia's effort to better understand dryland salinity and what might be done to manage, improve or prevent it. The NDSP provided a national forum for raising awareness and exchanging knowledge, bringing together many of Australia's leading hydrologists, soil scientists, agronomists, economists, social scientists and policy advisers. The program ran over the period 1993-94 to 2002-03. The first phase ended in 1997-98 and the second phase was completed in 2002-03 with a harvest year completed in 2003-04.

The program was managed and financially supported by various Commonwealth and State Government Departments and Agencies (e.g. Department of Agriculture, Fisheries and Forestry Australia, Land and Water Australia, the National Land & Water Resources Audit, Meat and Livestock Australia).

5.2.1. Objectives (www.nlwra.gov.au)

At the beginning of the program only a very small proportion of affected land had been treated with tree planting. In this start-of-program survey, the control technologies on which information was sought included:

- Tree/shrub planting in recharge areas and between recharge and discharge areas
- Perennial pasture improvement
- Cropping management
- Structures to divert water from recharge areas or to reduce waterlogging
- Establishment/or utilization of salt tolerant plant species
- Exclusion and/or controlled stocking to promote regeneration
- Use of sacrificial areas
- Aquifer pumping to lower watertables
- Sub-surface drainage to lower watertables

The magnitude and duration of the NDSP meant that it was instrumental in raising understanding and awareness of dryland salinity among Australians. This has already led

to more appropriate use of potential solutions to salinity such as reduced tree clearing, revegetation, greater use of deep-rooted perennial species, and some engineering work (Dept. of Agriculture, National Land and Water, Water and Rivers Commission, 2001).

5.2.2. Phase One

The first phase focused on improving the understanding of the causes of dryland salinity, and the second phase investigated extent, costs institutional arrangements, management solutions and landscape processes. The goal of phase two was to research, develop and extend practical approaches to effectively manage dryland salinity across Australia (NDSP, 2002).

5.2.3. Phase Two

43 projects were funded right around Australia in phase two. The overall cash investment was about \$ 10 million in the first phase and \$ 24 million in the second one. In the last year (2003-04) the emphasis was on harvesting and synthesizing the findings from the program (ADSP, 2001).

A wide range of outputs was produced from both phases of the program, including reports, data and knowledge, costs of salinity, communication products including demonstration sites, decision-support tools, mapping, technologies and models. While some new management systems and technologies were developed, many were not cost effective enough. However, NDSP frameworks such as the Groundwater Flow System are used as the basis of most State salinity strategies and continue to influence modelling and further research.

5.2.4. Salinity Survey (Water and Rivers Commission, 1998, www.salinity.com)

Some evidence that Australian farmers were taking action to manage salinity were provided in the ABS salinity survey carried out in 2002 across both dryland and irrigated farms. ABC state that a key finding was that nearly 30 000 farms had changed land management practice to manage or prevent salinity. The type and extent of land management practices undertaken wholly or partly for the prevention of salinity are shown in the table below (Fig.62).

State	Crops, pastures and fodder plants sown for salinity management ('000ha)	Trees planted for salinity management ('000ha)	Land fenced from grazing for salinity management ('000ha)	Earthworks undertaken for salinity management ('000ha)
New South Wales/ACT	1096	91	17	43
Victoria	680	40	40	37
Queensland	331	126	27	15
South Australia	452	14	29	13
Western Australia	633	500	352	98
Tasmania	7	5	1	3
Northern Territory	6	-	-	-
Total Australia	3205	776	466	208

Fig.62, NDSP, 2002

5.2.4.1. Key Findings

As a result of the 'Harvest' year six principal findings were filtered out:

- 1 salinity costs are significant and rising, hence responses must be strategic
- 2 profitable options for reversing the trend are lacking but under development
- 3 there is no one salinity problem – it challenges to look beyond traditional policy instruments
- 4 integrated catchment management must be seen as only an approach to deal with dryland salinity
- 5 vegetation management remains the key to managing water resources, although the benefit to cost ratio of revegetating catchments requires careful analysis
- 6 lack of capacity is an important but secondary constraint to managing salinity

The NDSP also played an important role in raising awareness of land managers and policy makers of the salinity problem. It forwarded the report to the Prime Minister's Science, Engineering and Innovation Council, which then assisted the case for the National Action Plan for Salinity and Water Quality (NAP).

The extent of land use change required to contain dryland salinity was found to be much greater than previously thought, especially in Western Australia, because of its hydrology and the position of the large regional groundwater basins. Also, where watertables can be controlled, response times from intervention activities (e.g. planting trees) to positive impacts (e.g. lowering of watertable) could be very long, taking, for example, several decades. It was concluded that responses will vary depending on the hydrogeology of the area as well as on its soils and climate (www.countryman.thewest.com.au).

In conclusion, the investment led to useful information on understanding salinity and the cost of salinity but did not make a major contribution to cost-effective solutions. Such solutions may still be another 5-10 years away (www.salinity.org.au; Oliver, 1999).

5.3. Sustainable Grazing on Saline Land

Land Water and Wool was a five and a half year research and joint venture program between Land & Water Australia (LWA) and Australian Wool Innovation Limited (AWI) that ran from September 2001 to March 2007. Sustainable Grazing on Saline Land is one of the sub-programs and has operated as a partnership with CRC for Plant-based Management of Dryland Salinity (Cooperative Research Centres for Salinity), Meat and Livestock Australia, State based agriculture and conservation agencies, and farmers across southern Australia (www.brs.gov.au).

The program had projects based in 5 States with about 120 farmer research sites with emphasis on:

- salt and water movement from saltland
- siting, establishment and performance of saltland species
- performance and utilization of saltland pastures
- biodiversity impacts from saltland pastures
- economics of saltland pastures

A budget of A\$ 300 000 was made available for this project, which finally should become the essential reference for saltland management for the next several years. It should also get the on-going support from State based agricultural and conservation agencies, regional natural resource organizations, company and private agronomists and Future Farming Industries CRC (National Saltland Service; www.crcsalinity.com).

5.4. Other Projects:

5.4.1. Australian Special Rural Research Council and Australian Water Resources Advisory Council

The two Councils are working together on developing feasible management options for sustaining environmentally sound irrigated agriculture together with the local rice industry.

5.4.2. Division of Water Resources

The Division of Water Resources is developing a better understanding of the behaviour of shallow water tables and associated waterlogging and salinisation of irrigated areas in southeastern Australia. Crops such as rice, wheat, soybeans and pasture, strongly influence regional water balance. Because rice culture includes a prolonged period of ponding, such areas function as major recharge zones to the watertable, whereas crops such as wheat and soy beans can obtain from 9 – 20% of their water from capillary rise and may act as major discharge zones. Computer simulation is used to estimate these fluxes of water and salt to and from water tables. These simulations are calibrated and are extended to examine field situations and management options.

The work of developing feasible management options for sustaining environmentally-sound irrigated agriculture is being supported by the local rice industry in conjunction with the Australian Special Rural Research Council and the Australian Water Resources Advisory Council (CSIRO, Rural Sector Report, 2004).

5.4.3. CSIRO Division of Water Resources

CSIRO Division of Water Resources together with state and federal agencies is involved in various projects dealing with groundwater management, interaction between groundwater and surface water, effects of land use and irrigation and dryland salinity management. These researches are ongoing including testings and assessments of growth and yield models.

5.4.4. Catchment Demonstration Initiative and Engineering Evaluation Initiative

The Catchment Demonstration Initiative is a program by the Government of Western Australia, the Commonwealth and regional groups to demonstrate viable salinity management systems as part of the National Action Plan for salinity and Water Quality. This Initiative is a A\$6 million joint State and Commonwealth Government program for agricultural areas in Western Australia. It aims to convey its outcomes in targeted, large-scaled, catchment-based demonstrations of integrated salinity management practices.

CDI will complement the Engineering Evaluation Initiative by including various engineering options. The projects include catchment regions in the southwest of the state and in the northern agricultural region (e.g. Avon River, Moore River, Fitzgerald River catchments). Funded are: planting of perennial pastures and woody perennials, oil mallees and saltbush; the protection of riparian and remnant vegetation, commercial farm forestry, salt land grazing and water management systems in the catchment areas.

These funds will deliver realistic catchment scaled demonstrations of salinity management options for farmers, which after their evaluation can be accessed (CSIRO, 2004).

5.5. Salinity Damage to Assets

It has to be considered that salinity not only affects agricultural areas but also spreads to rural townships in low lying positions like in the southwest of Western Australia, where towns like Merredin, Katanning, Narrogin, Wagin, Merredin are affected. Not only has already about one third of the fresh water supply in the region become brackish or saline and can no longer be used (the largest river in the southwest, the Blackwood River, has become unsuitable as a water source for drinking water), but rising saline water tables have also started damaging roads, buildings, foundations and other infrastructure (Lyons, 1995; Matta, 1999; National Dryland Salinity Program, 2002).



Fig.63, salt damage to buildings, photo by author, 2007



Fig.64, salt damage to roads, photo by author, both

Fig.63 and Fig.64 show the results of salt damage to buildings and roads. The effects of high watertables and salinity is often most evident as rising damp in building walls which can lead to breakdown of mortar.

5.5.1. Merredin, a salt-affected Town (National Dryland Salinity Program, 2002)

Merredin, 230 km east of Perth, was one of the first towns to join the Rural Towns Program, initiated under the Western Australian State Salinity Action Plan in 1997. More recently, it was one of six towns subjected to a detailed economic impact study. To assess costs from damage by rising groundwater to residential buildings and other infrastructure was like heading into uncharted territory. After extensive consultation, some estimates

were put on damage to various types of infrastructure. Predictions include \$ 6 000 per brick house in the third year after groundwater reaches within 0,5 m of the surface, to pay for building perimeter drains or other means to discharge groundwater. A further \$ 2000 is estimated to repair brickwork and crumbling mortar in the first year (CSIRO, 2005).

But the big salinity damage costs are for repairs and maintenance to roads. Best estimates based on national experience suggest that additional road maintenance due to very shallow saline water tables will be up to \$ 195 000 per kilometre every three years for highways and \$ 100 000 for local sealed roads within towns.

Groundwater models for the town of Merredin indicate that annual groundwater rise of 0,1 to 0,2 m will affect about one third of Merredin at some stage over the next 30 years unless action is taken. Damage costs will be about \$ 400 000, with 70% required for additional maintenance of roads and railways (Matta, 1999; Short, 2000).

Groundwater pumping and saline water disposal are evaluated using evaporation ponds and desalination. Improved stormwater management will be required to reduce contribution to groundwater recharge and more efficient water use by householders, e.g. garden watering only when really necessary, limited lawn area – they need the most water, proper roof drainage – connected to stormwater system (Dept. Agric., 1997;2006).

5.5.2. Assets at Risk of Salinity Damage

Summary of assets in areas at high risk from shallow watertables or with a high salinity hazard

Asset	2000	2020	2050
Agricultural land (ha) ¹	4 650 000	6 371 000	13 660 000
Remnant and planted perennial vegetation (ha) ^{2,4}	631 000	777 000	2 020 000
Length of streams and lake perimeter 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	306	5 100
Important wetlands (number) ⁴	80	81	130

Fig.65, ANRA, 2000

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 Much of the remnant and perennial vegetation reported for each State occurs on agricultural lands.

5.6. Conclusion

As pointed out in this paper there are numerous government programs in place across Australia, which intend to promote conservation of land and water resources. Although salinity is one of a number of causes of resource degradation, it is increasingly being seen as the most serious and important of them, as reflected in the growth of major policies and programs targeted specifically at salinity.

The State Salinity Councils have been working on setting priorities for public investment in salinity management for:

5.6.1. Priorities for Public Investment

- **Prevention** (planting of deep rooted perennial plants, using shallow drainage systems to divert water before it enters the groundwater)
- **Remediation** (lowering the groundwater table on a large scale – even though technically difficult and economically hardly viable)
- **Adaptation** (using deep open drains, pumping, salt-tolerant plants, salt-resistant infrastructure and desalination) (NDSP, 2004)

Funds are channeled towards further research, development of new technologies, engineering works, monitoring, and directly to farming managers to help establish land use changes on site. Subsidies to farmers should be an incentive to plant more perennials and to adopt salinity management programs.

5.6.2. Do farmers bear too much Responsibility for their Land?

Farmers want to ensure sustainability of their land which is a big responsibility in a continent with most variable rainfall worldwide. Governments demand farmers to use land to produce wealth, create jobs and exports; but nowadays environmental issues become more and more dominant. A careful balance is needed when economic, social and environmental impacts are taken into consideration; a balance between environmental values, production values and use of resources. Governments should compensate farmers for the environmental burden they have to carry. With falling meat and wool prices and improved farming techniques, cropping seems quite an attractive alternative most of the time. The authorities usually still give their permission to clearing the land when farmers want to sow crops; compared to the value of crops the value of native vegetation is not really viable (www.agric.wa.gov.au; www.affa.gov.au).

Australian farmers have always shown initiative when faced with new challenges. Dryland salinity is one of the greatest challenges yet to confront the farmers, but again most of them are rising to the occasion. On the agricultural land showing signs of salinity most of the farmers are now implementing salinity management practices. The main motivations for it are – farm sustainability, environmental protection and maintaining of agricultural production. The main barriers to changing land management practices are lack of financial resources and lack of time. Lack of information or doubts about likely success are not considered to be a barrier to change (ABS, 2003).

There exist various state and national organizations for farmers as well as different publications, magazines and newsletters that keep them informed about failings and success in tackling salinity. In regular statewide meetings and conferences a diversity of approaches to salinity management in different environments are discussed and exchanged. This networking that had been encouraged by the National Dryland Salinity Program has become invaluable in enabling farmers to share their experience and learn from each other.

The ticking away of the salt time bomb beneath Australia's agricultural land should not have surprised anyone. Already in the middle of the 19th century a convict superintendent near York in Western Australia commented on water being too saline for animals so that they had to rely on well water. He recorded that in his opinion subsoils were containing the salt left behind by evaporation (www.csiro.au; www.audit.ea.gov.au).

In 1917 a professor in agriculture at the University of WA presented soil samples and a report to the Royal Commission on Mallee Land, referring to woodland in the Esperance area in the southwest of WA. He claimed that probably one third of the area considered for development was too saline for profitable farming. The response he got was: "...the Commission having given the question close consideration, strongly urges that scientific prejudice against our mallee lands be not permitted to stand in the way of their being opened up for agricultural purposes." And the clearing continued.....! (www.csiro.au)

Australia still remains one of the top land clearing countries of the world. How much vegetation is being removed is unclear. It is assumed that there is still lots of illegal clearing going on, or clearing under certain exemptions, which could be up to 30% of the yearly rate (80 000 ha/year). Salinity, loss of biodiversity and land degradation are part of the price to pay. One can only hope that finally common sense will prevail and all members of the community will act accordingly.

Striving for a better life has put unprecedented pressure on water resources. These pressures are placed on every part of the water cycle, and can affect the amount of water harvested from catchment areas, drinking water, and the life in the rivers and oceans.

Governments and communities need to work together to protect Australia's unique environment and the future health of its natural resources. All Australians will benefit from environmental, social and economic improvements by collectively tackling salinity and declining water quality.

This newspaper article from the biggest newspaper in Western Australia (The West Australian) from April 2008 shows the desperate situation farmers are facing with increasing salinity on their farmland and the measures which have to be taken to combat one of Australia's biggest environmental problems.

Salinity and its effect on land and water is regularly in the headlines and will stay there for many years to come (The West Australian, 2008).

THE WEST AUSTRALIAN
SATURDAY, APRIL 26, 2008

News
5

Ambitious drains system cuts a 55km swath through 12 Dumbleyung properties in landmark assault on salt




Bold bid: Landcare officer Rebecca Walker at Lake Dumbleyung. The ambitious scheme spans 12 farms. Pictures: Greg Burke

Man on a mission: Damien Gooding stands in a drain on his property.

Farmers declare war on ruinous salinity

JODIE THOMSON

Farmers have carved 55km of drains through land in the Great Southern as part of a landmark project to protect their properties from spreading salinity.

The ambitious scheme, which spans 12 farms near Dumbleyung, has taken more than eight years to complete with much time spent overcoming planning hurdles linked to the use of deep drainage, which remains a contentious method for combating one of WA's biggest environmental problems.

About 1.1 million hectares of WA land is salt-affected, growing at a rate of about 14,000ha each year, or the equivalent of 19 football ovals a day.

Drains averaging 2m deep have been installed to move ground and surface water downstream, where it eventually flows into an already saline creek forming part of the Lake Dumbleyung, a salt-affected lake system. They will protect an estimated 6,655ha of farm land which are

already salt-affected or at risk from salinity by managing groundwater levels.

Gordon Davidson, Dumbleyung Shire president and the farmer behind the pilot project, concedes that at a construction cost of about \$1.5 million, or \$27,000 a kilometre, the scheme is not cheap. But he argues the cost of doing nothing would be far greater.

"We can't afford to have the land go any saltier, we can't take any more of it," he said. "We have to remove some of the water out of the valley floor so that we can gain some ground. If we don't we will finish up with bare salt scalds, and that will create a worse environmental problem."

Proponents of drainage argue that while revegetation may be effective on the upper parts of a catchment area, the most effective way to shift salty water through the valley floor is by using deep drains. But debate often surrounds where to move the salty, and sometimes acidic, water. In many cases it is down-

stream, through other farm properties.

While other drainage systems have been done on a multi-farm scale, this project is the first to collect comprehensive data on the impact of drains and involve collaboration between farmers and multiple government agencies.

About 44,000ha, almost a third, of the Dumbleyung sub-catchment is affected by salt or at risk of salinisation. Mr Davidson said the project, which has been part funded through the South-West Catchment Council using National Action Plan for Salinity funds, had involved extensive consultation and research work.

The data and planning model used would be used to help future large-scale drainage projects and as a result, he expected future projects to be more cost effective.

Mr Davidson first installed drains on his property 10 years ago. "If we hadn't put them in, we would have lost probably 200ha by now," he said. "If you

looked at it, it probably would have been easier for me to just go and buy some land elsewhere, but that's not the way I work, I don't like to see things deteriorate and I think farmers generally are conservationists — they hate to see paddocks blowing away, they hate to see water erosion, they hate to see salinity."

Damien Gooding farms on the lowest property at the end of the drainage system, with 2.5km of drains running through about 230ha of salt-affected country on the farm.

"We could see the value of the drain going through the valley floor and to achieve its goal it had to go through our place," he said. "It won't enhance or reclaim a beneficial portion of our land, but if it's going to benefit other people up the catchment then we are happy to be part of it."

The Department of Water acting director of water resource management Tim Sparks said monitoring of water flows, salt levels and pH levels would continue.

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Abbreviation	Full Name
ABS	Bureau of Statistics
ANDSP	Australian National Dryland Salinity Program
ANRA	Australian National Resources Atlas
BRS	Bureau of Rural Science
CANA	Climate Action Network Australia
CRC	Cooperative Research Centres
CSIRO	Commonwealth Scientific and Industrial Research Organization
DAFF (AFFA)	Department of Agriculture, Fisheries and Forestry
NAPSWQ	National Action Plan for Salinity & Water Quality
NLWRA	National Land and Water Resources Audit

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7. Summary:

This paper deals with the ever increasing problem of salinisation in Australia. It is one of the biggest environmental hazards this country is facing today, one which will not go away.

Salinity naturally occurs in Australia, but the clearing of native vegetation and use of water for irrigated agriculture, domestic and other uses has caused the salt stored beneath the ground to surface in many areas. This has affected agricultural production and damaged civil infrastructure, such as buildings, roads and railways.

In most cases Australia's native vegetation consists of trees and woody shrubs. This perennial vegetation with its relatively deep rooting system has become effective at taking full advantage of any available water. As a result, it can use most of the water entering the soil from precipitation. The leakage of excess water into the deeper soil below the roots is usually quite small, if it happens at all. On the other hand, various studies have shown that over most of Australia's current dryland grazing and cropping areas with their shallow rooted annual crops and pastures, this leakage is much higher and can lead to wet and waterlogged soils, a rise in groundwater combined with bringing saline water from deep down to the surface.

The main focus of the thesis is directed to the link between land clearing and salinity which was becoming evident already by the end of the 19th century, even though unfortunately the severity of the problem was not recognized at the time and the thoughtless uncontrolled clearing of native vegetation for more and more farmland continued.

Today the salt affected areas are spreading so rapidly, especially in the most important agricultural areas in the country's southwest and the irrigated Murray-Darling Basin, that millions of dollars have to be spent annually to try to combat and halt the further expansion of salinity. The correlation of salinity and the slow response time of groundwater flow systems to changes in land use means that it can take hundreds of years for groundwater systems to reach a balance once all the excess water had left the system.

There are numerous government agencies and departments dealing with the salinity problem in a variety of different projects. Besides monitoring the spread and consequences of salinity, the aims of the projects are: to inform and educate farmers and farming communities about the negative effects of current agricultural practices, to help and support new land use systems, to encourage reforestation and to protect the land and the existing native vegetation.

Even if completely different farming systems are to be introduced Australia-wide immediately it will be a long time before an improvement in salt trends will be noticed.

8. Zusammenfassung

Die vorliegende Arbeit beschäftigt sich mit dem ständig zunehmenden Problem der Versalzung in Australien. Es ist eines der grössten Umweltprobleme mit dem sich dieses Land befassen muss, ein Problem, das sich nicht wegwischen lässt.

Versalzung des Untergrundes ist ein natürliches Phänomen in Australien. Das unkontrollierte Abholzen der bodenständigen Vegetation, übermässige landwirtschaftliche Bewässerung und die Verwendung von Wasser für Haushalt und andere Zwecke hat das Salz aus dem Boden an die Oberfläche gebracht. Dadurch werden nicht nur landwirtschaftlichen Nutzflächen sondern auch Gebäude und Infrastruktur (Strassen, Eisenbahnen), betroffen.

Australiens natürliche Vegetation besteht hauptsächlich aus Bäumen und holzigem Buschwerk. Dieser permanente Pflanzenwuchs mit seinem tiefreichenden Wurzelsystem nutzt den verfügbaren Niederschlag fast zur Gänze, sodass kaum Wasser an den Wurzeln vorbei in tiefere Lagen gelangt. Andererseits haben diverse Studien gezeigt, dass in Australiens gegenwärtigen landwirtschaftlichen Nutzungszonen (Getreideanbau und Viehwirtschaft) mit ihren flachwurzelnden einjährigen Pflanzen viel mehr Wasser in die Tiefe sickert. Daraus resultieren nasse sumpfige Böden mit steigendem Grundwasserspiegel, der das Salz aus der Tiefe an die Bodenoberfläche transportiert.

Das Hauptaugenmerk dieser Diplomarbeit wird auf den Zusammenhang von Abholzung und Bodenversalzung gelegt. Schon Anfang des 19. Jahrhunderts wurde dies offensichtlich, obwohl leider die Wichtigkeit dieses Problems nicht erkannt wurde und die unkontrollierte Abholzung der bodenständigen Vegetation weiter fortschritt.

Heute nimmt die Bodenversalzung dermassen zu - besonders in den von Landwirtschaft intensiv genutzten Flächen im Südwesten des Landes und im Murray-Darling Becken - dass Millionen von Dollar jährlich ausgegeben werden müssen um der weiteren Ausbreitung Einhalt zu gebieten. Die langsame Reaktion des Grundwasserflusses bei Änderung der Landnutzung bedeutet, dass es hunderte Jahre dauern kann bis das überflüssige Wasser das System verlassen hat und eine Balance im Wasserhaushalt erreicht ist.

Viele staatliche Institutionen befassen sich mit der Versalzung in diversen Projekten. Neben der Beobachtung der Versalzung und deren Auswirkungen haben diese Projekte zum Ziel die Farmgemeinden über die negativen Auswirkungen der gegenwärtigen Anbaupraktiken zu informieren und neue Anbaumethoden sowie Aufforstung, Erhaltung von Boden und Naturbuschland zu unterstützen. Aber selbst bei einer sofortigen totalen Umstellung der gegenwärtigen Agrarwirtschaft in ganz Australien ist eine wesentliche Besserung im Versalzungstrend nicht unmittelbar absehbar.

9. Resume

PERSONAL DETAILS

Kralupper Karin

Born on June 5, 1948, in St. Johann/Pongau, Salzburg

Unmarried

Citizenship: Austria and Australia

EDUCATION

1954 – 1958	Primary School Rauhensteingasse 5, 1010 Vienna
1958 – 1966	High School (Realgymnasium) Rahlgasse 6, 1060 Vienna (Matura 1966)
1966 – 1972	University of Vienna, study of Geography and History
1972 –	Migration to Perth, Western Australia

FURTHER EDUCATION AND TRAINING

1977 – 80	Study of Social Science at Western Australian Institute of Technology
1985 – 88	Courses: computing for new users, acting/drama course

EMPLOYMENT HISTORY

1972 – 1977	Laboratory Assistant at Blue Cross Products (Chemical Factory)
1977 – 1980	Bar Manager in various clubs (ethnic German/Austrian clubs, soccer club)
1980 – present:	among other things, German Teacher at night school, Tourist Guide, Secretary/personal Assistant in Catering Business and various Hospitality Businesses, Secretary/Editor – issuing newsletter /Radio speaker/Entertainment officer for ethnic communities
1993	return to Vienna and since then commuting regularly between continents, restarting Geography studies at the University in Vienna, working part time at Vienna Opera and Vienna airport.

LANGUAGES

Oral and written English, some French

EXTRA CURRICULAR ACTIVITIES

Member of committee of “Auslandsösterreicher-Weltbund”, head organisation of all Austrian clubs worldwide; very much involved in social work