CONSERVING LAND AND WATER FOR SOCIETY: GLOBAL CHALLENGES AND PERSPECTIVES

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Abstract
In the next 30 years, developing countries will need an additional 120 million ha for crops. They are likely to expand their irrigated area from 202 million ha today to 242 million ha by 2030; requiring a 14 percent increase in water extracted from surface water and groundwater resources. Although there is enough water available at global level, the volume per head is falling sharply. Some regions in Africa and Asia will face serious water shortages. One in five developing countries will suffer water scarcity. Current analysis is limited, but it is clear that both land and water will come under greater pressure and become increasingly scarce. Even though the consequences of continuing degradation of the global environment have been somewhat underestimated in the work reported here, the results strongly suggest a decline in the capacity of the global food production system to feed the growing world population. The challenge is renew efforts to find farming systems and land use patterns that can increase productivity while greatly reducing damage to the resource base and the wider environment. This requires integrating biophysical science with economics and social sciences in ways that engage the community and give confidence for institutional and policy innovation and reform.

Additional Keywords: Degradation, ecosystem, conservation farming, irrigation, productivity, Australian response

Introduction
Faced with serious damage to rivers, catchments and landscapes, global societies are increasingly tackling the challenge of finding new ways to produce food and fibre that do not damage the land, water resource and ecosystems on which that long-term productivity depends.

One does not have to be directly involved in land management to be keenly aware of increasing concerns about natural resources: their use, abuse and decline. Human needs for food, fibre and shelter have led to practices and processes that have had enormous effects on the land, water and biodiversity of our ecosystems. (Williams 1991; Kendall and Pimentel 1994; Chartres and Webb 1998). The processes causing concern are not restricted to particular parts of the production or consumption chain. Clearing for industrial and urban development can have as much effect on vulnerable species and biological diversity as logging or clearing for agriculture; sediments, chemicals and wastes can pollute the environment whether they arise from industrial, agricultural or mining operations, or urban areas.

With the exception of some quite rapid phases of soil erosion promoted by farming practices, drought, and plagues of rabbits (in Australia) or insects, much of the degradation has been insidious and often hidden beneath the ground surface. In many instances we have not realised that changes to the land can reach critical thresholds beyond which processes start to seriously affect the health and quality of our river systems. Thus, in-field farm management practices can set in train processes that not only result in land deterioration but eventually, loss of water quality and deterioration of our aquatic and near-shore environments. For example, we can observe such a ‘degradational cascade’ in Australia following replacement of native woodlands with annual pastures. In many instances this has led to increased groundwater recharge, rising saline water tables, intersection of the groundwater table with the land surface, seepage of salt into adjacent streams, and migration of that salt downstream. On-farm management can have effects downstream, such as an accumulation of salts, sediments and nutrients and reduced diversity of aquatic biota. The resulting problems in water quality affect rural dwellers and people who live in our coastal cities and towns. Of equal concern is the sedimentation of near coastal water, pollution of fishing grounds, and despoliation of natural environments such as wetlands and, in Australia, world heritage features such as the Great Barrier Reef.

The on-farm damage to the natural resource base on which productivity ultimately depends has been the traditional focus of our thinking. Over the past decade, the capacity of our natural resource base to meet ever-increasing pressures on food and fibre production technologies to satisfy increasing demand from global population growth has received much attention (Kendall and Pimentel 1994; FAO 1995; Pimentel 2001). While the exact nature and timing of food production limits is uncertain, there is increasing evidence that within the next 50 years, the human race will be getting close to the limits of global food productive capacity based on present technologies. Substantial damage already has been done to the biophysical systems that we depend on for food production. An analysis by Professor Bo Doos (undated), which seeks to balance the loss in productivity by natural resource degradation against technological gains and increased areas of production, suggests that over the period 1990–2025, the average value of the expected increase in grain production is estimated to be 37 million tons a year.

This figure is likely to be constant over the period to 2025. Over the same period, the average loss in grain production from natural resource degradation is estimated to be 19 million tons a year. The losses will be greater towards the end of the period. The average net gain over the period is 18 million tons a year. This is about 1 percent of present annual grain production. Due to the increase in losses over time, the net gain will diminish in time and by the end of the period will probably be much lower than this value and approach 0.5 percent.

The concept in this analysis is set out in Figure 1 and Figure 2 below.

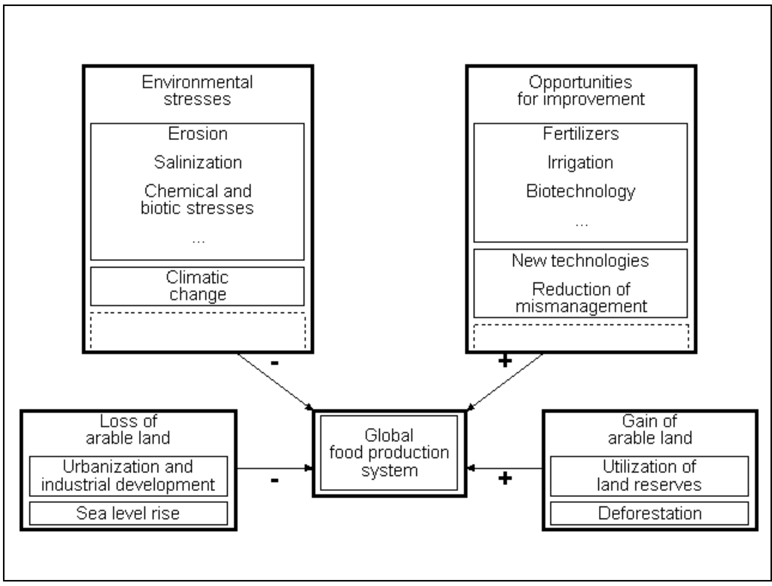

Figure 1. Schematic analysis of factors that determine global food production (Doos undated)

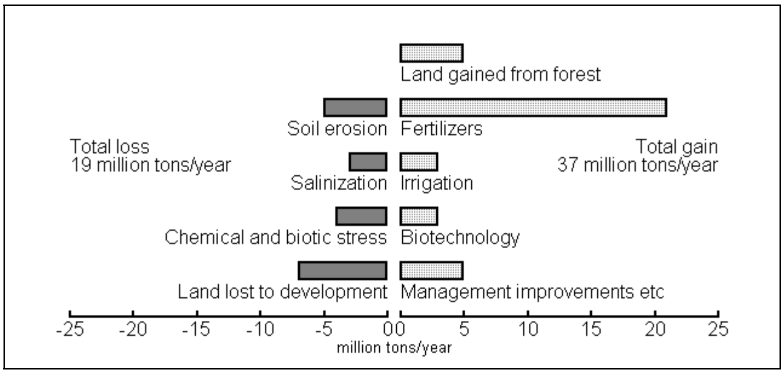

Figure 2. Schematic gains and losses balance out to yield the global food production. (Doos undated)

Despite the limitations of the work, two conclusions can probably be drawn with some certainty:

- unless steps are taken to reduce environmental degradation and at the same time make more systematic use of existing opportunities to increase grain production, it is likely that the present net gain of about 1–2 percent a year will decrease to about 0.5 percent a year within the next few decades; and
- comparing the estimated rate of change in world grain production with the rate of change in world population—1.73 percent a year at present to 1 percent a year in 2025, according to the UN medium variant projection—reveals a widening gap between the expected demand and production of grain.

It is against this global background of food and fibre production pressures on land and water resources that this review of global challenges and perspectives is cast.

Food production, ecosystems and natural resources

Why has degradation occurred?

Chartres and Webb (1998) set out a very valuable analysis of the impacts of farming action on catchment reaction from which this work draws significantly. Research into the natural environment over the past two to three decades has been partly responsible for change in our understanding of agricultural systems. Rather than being regarded as different and separate from the 'natural environment', we now perceive agricultural systems to be governed by the same ecological principles and processes that apply in natural landscapes. Agricultural systems are modified ecosystems; accordingly, the term 'agroecosystem' has been coined. The broad processes involved in ecosystem functioning are the movement of energy, water and nutrients. In agricultural landscapes, the introduction of farming practices has not only resulted in direct change to the biota, with a loss of native plants, animals and the introduction of exotics, both desirable and pest, but has also had a marked effect on these processes. As a result, their rates and patterns vary considerably from those before the particular farming systems were established. Changes in these processes have, in turn, had a further effect on soil and land properties, in many cases reducing their capacity to support previous levels of growth and yield as well as the same variety of plants and animals.

Now that we realise that agricultural systems are governed by the same ecological processes that operate in the landscape as a whole, we have become aware of the interconnections between the various components of the system. Processes of water, nutrient and energy transfer result in integration of the vegetation, land and water resources. We cannot alter these processes in one part of the catchment without it having ramifications in other parts as the system establishes new balances.

The ways in which the production system interacts with water and nutrient cycles, and the implications of these interactions for longer-term stability and sustainability, have previously been neglected or studied in isolation from the production system. The focus on short-term soil, plant and/or animal productivity and neglect of other components of the ecosystem has been a primary cause of land degradation. The first step in our search for ecologically sustainable agriculture is to consider the agricultural production system in the context of the landscape in which it occurs.

Effects of agriculture on the land resource

The major direct effects of agriculture can be linked to the underlying processes that have been altered. For example, increased waterlogging and salinity result from changing the fluxes of water associated with different components of catchment water cycles; structure and erosion have declined as a result of reducing the protective cover of soils and increasing their exposure; and addition of chemicals has led to pollution.

Agriculture has a long list of effects on land resources, although each one is not of equal seriousness. It is almost impossible to quantify the impacts each form of degradation has on the 'productive capacity' of the land because of the difficulty in separating impacts of land degradation from those of rainfall variations, crop breeding and other influential factors. Societies all over the world face a demanding task in building productive land-use patterns that are in harmony with their environment and able to support sustainable urban and rural communities. If we fail to address this urgent task in an integrated, inclusive and adaptive way, the outcome will be further losses of biodiversity, land and water degradation. Over the long term, this will threaten wealth generation, amenity and social wellbeing.

The following discussion treats the main forms of land degradation (see Chartres and Webb 1998; Williams 2001) with an Australian emphasis, but they apply in most instances across the globe:

1. Loss of biodiversity, fragmentation of habitat, particularly on the more productive soils

Caused by clearing and grazing, which has reduced the area of native vegetation and associated fauna. In Australia, exotics have invaded native vegetation from farmland and fragmentation has interrupted ecosystem function. In addition, salinisation and the use of pesticides have affected remnant native vegetation. Vegetation management has reduced biodiversity, resulting in extinctions and loss of characteristic species and communities. Changes to natural ecosystems have also disrupted population dynamics and allowed some pest species to have a greater effect. This is particularly so in Australia.

2. Deteriorating soil quality

This is the result of the following factors:

Changes and decline in soil biota
Caused by changes in soil condition as a result of cultivation, a decline in organic matter that provides the food source, and the application of herbicides and other pesticides. Soil organisms are critical to the breakdown of organic matter and the cycling of nutrients, and perform other important functions. Decline in their total biomass, loss of species diversity and/or the favouring of particular species groups (e.g. herbicides can affect the balance between fungi and bacteria) can cause loss of important processes.

Nutrient decline
Caused by removal of nutrients in agricultural products, leaching and erosion, and failure to add sufficient fertilisers, composts and manures to replace lost nutrients. Loss of organic matter through frequent cultivation and insufficient replenishment reduces the nutrient-holding capacity of the topsoil and exacerbates leaching losses. Loss of nutrients leads to reduced plant yield, produce quality (e.g. grain protein) and animal vigour.

Soil acidification
Caused by mineralisation of fertiliser ammonium and atmospheric nitrogen fixed by legumes, followed by leaching of nitrate not then used by plants, and associated cations; and also by alkali export in products such as hay, grains, meat and wool. Acidification reduces crop and pasture productivity by removal of nutrient cations, decreased availability of phosphorus, and increased availability of toxic elements such as aluminium and manganese.

Soil structural decline
Caused by compaction by machinery and animals, inappropriate cultivation (too often or under too wet conditions) and inappropriate grazing management (stocking rates too high for pasture condition). Loss of organic matter is a major factor. Loss of structure reduces the capacity of the soil to store water and can directly inhibit root and shoot growth; increased erosion can occur as a result of the increased runoff and reduction in plant cover.

Soil pollution by pesticides and heavy metals
Caused by chemicals used to control weeds and pests in crops and pastures and to maintain animal health, application of fertilisers with increased cadmium concentrations and other contaminants, and sewage sludge containing heavy metals. The problems have increased with more mechanisation and broadacre cropping and, more recently, with minimum tillage. Use of chemicals can increase the incidence of root disease, induce weed resistance, reduce nitrogen fixation and nutrient uptake, and affect the soil biota.

Soil erosion
Caused by exposing the soil surface to wind and water movement and reducing surface roughness and soil aggregate stability. Wind, sheet and rill erosion removes surface soil that usually has a higher organic matter and nutrient status than the subsurface soil. As a result, productivity is decreased as plants are established in the less fertile subsurface soil, the water-holding capacity of soil is reduced and ultimately, the soil resource is depleted. Gully erosion delivers large amounts of sediment and nutrients to rivers and streams.

Waterlogging and salinisation
Caused by changes to components of the water cycle through replacement of deep-rooted perennial species by annual plants; salinisation is a problem when changes in water movement pathways occur where salts are saved in the regolith. Waterlogging and salinisation reduce or prevent growth of crop and pasture plants; increased erosion can occur when lack of plant cover increases runoff in salted areas.

Effects of agriculture on water resources
We judge the global water resource by its quantity and quality. Quantity is largely controlled by the amount and timing of rainfall, the amount of storage in reservoirs, and the amount taken for domestic, industrial and agricultural consumption. The quantity of water available for storage is affected by vegetation cover. In large catchments with high rainfalls, vegetation cover can have a significant effect on the rate and amount of runoff where stream flow is dominated by groundwater and recession flow. Converting forest to grassland in catchments where there is significant recession flow usually results in increased water yield (Zhang et al. 1999).

Agriculture is a profligate user of water. In Australia, for example, we use 21,000 GL of freshwater every year, of which more than 75 percent is used for irrigation. Extracting water from rivers and catchments for irrigation usually has a profound impact on river flow regime, wetlands, floodplains and estuaries. In southern Australia, water extraction for irrigation has reversed normal flow patterns (i.e. rivers are full to the banks in summer as they deliver irrigation water and are low in winter as storages are replenished). This has had profound consequences for the ecology of waterways, including favouring exotic species such as carp (Cullen and Bowmer 1995). Elsewhere, over-extraction has diminished total flows and helped stimulate the development of blue-green algal blooms where nutrients are available. The effect of water extraction for irrigation on catchment and river health cannot be ignored. We also need to be aware that, if irrigation levels stay constant, other well-intentioned catchment management actions might have unexpected adverse reactions. For example, we can envisage scenarios where major tree-planting schemes to combat local salinisation, or for purely economic reasons, might use more water and reduce the inflow of freshwater to streams, exacerbating the already low flows in some catchments. Elsewhere, in different environmental settings, well-located tree planting may have advantages in reducing the accession of saline waters to river systems.

Water quality can be substantially affected by the nature of vegetation cover in a catchment. Runoff from exposed soil carries sediment, organic matter, phosphorus, nitrogen, metals and pesticides. Some of these materials reach rivers, lakes, wetlands, reservoirs, estuaries and the ocean. Salinisation of soil and water results from converting forests and woodlands to crops and pastures. Water quality, however, is not just affected by the state of the land. Most rivers are formed in sediment, and the state of that sediment is crucial to the quality of river water. If the banks and riverbed are unstable because of grazing, clearing, exotic species or pollution, then the river water will be muddy and possibly unusable. The construction of weirs and reservoirs has produced large and sometimes shallow bodies of still and often warm water, ideal for the growth of cyanobacteria. Maintaining high quality water is vital, but poses numerous management problems.

Following is brief summary (drawn from Cullen and Bowmer 1995; Chartres and Webb 1998) of key forms of decline in water quality and quantity:

Loss of habitat and exotic invasions
Caused by clearing and grazing of riparian zones, and the introduction of exotic plants. Not only has this had a marked effect on the native riparian flora and fauna; it has also influenced the aquatic biota through changes to habitat (e.g. through changes to the microclimate, or adding sediment from bank erosion) and to the type, amount and seasonality of organic matter food supply added to streams.

Changes in river flow regimes
The major cause is storage and extraction of water for irrigation and urban use, resulting in loss of essential environmental flows. Usually, this radically changes the wetting and drying of wetland, floodplains and the river channel itself. As a result, the functioning of these riverine landscapes, lakes and estuaries is profoundly altered, causing loss of ecological function, river health and consequently, water quality.

Eutrophication
Eutrophication is nutrient enrichment that can result in excessive growth of algae and macrophytes. Growth is stimulated by runoff containing phosphorus and nitrogen, while certain types of organic matter can be a food source for sulfate-reducing bacteria that can be involved in the release of phosphorus from storage in bed sediments. Eutrophication can be exacerbated by management strategies for water bodies and reduced river flows caused by irrigation.

Pesticide pollution
Caused by direct accessions of pesticides from aerial spraying or from drift from spraying close to water bodies; and indirect accession in runoff water, often with pesticide attached to organic and mineral particles.

Salinisation
Caused by movement of salt from salinised land or the direct seepage of saline groundwater to rivers through their beds and banks. Changes to land use in catchments causes groundwater hydrology to move saline water to the

stream. Increasing salinity of water can limit its use for domestic, industrial and agricultural purposes; it can also harm the aquatic biota.

Turbidity and sedimentation
Caused by erosion of riverbanks and sheet, rill and gully erosion. Turbidity is exacerbated by naturally very fine clays and is most important in Australia. Sediments increase the need for water treatment and the fine sediments carry phosphorus, metals and pathogens. Sedimentation reduces the storage capacity of dams and reservoirs and affects the ecology of dams, estuaries and near-shore habitats. It is a major cause of ecological damage to Australian rivers.

Spatial extent, trends, and productivity and biodiversity losses due land and water degradation are poorly documented, and it is often difficult to assess the extent of land degradation. The problem can be masked by farmers converting their land use to less demanding production. Where soils are deep, the effects of erosion may not be noticed until the absence of soil becomes a limiting factor for production. It is possible to measure degradation costs as the cost of replacing lost nutrients, the value of the lost yield, the value of increased farm inputs required to maintain yields, or as the cost of rehabilitating the land (Scherr and Yadav 1996).

Nevertheless, during the 1980s, the broad dimensions of land and water degradation across the globe were identified and regularly examined in terms of form and process. The spatial extent, trends, and the costs in lost production and loss of environmental amenity, particularly biodiversity, remained very poorly documented until recently (e.g. Scherr and Yadav 1996; 1997), although the information remains less than adequate for large areas of the globe. In Australia, it was only late in 2002 that the National Land and Water Resources Audit Report, *Australians and Natural Resource Management 2002,* was published and improved our knowledge considerably. Other important documents (Virtual Consulting Group and Griffin NRM, 2000 and Morton *et al*. 2002) published near this time were also important in Australia.

Land: a global perspective
Soil and water are two of the most precious resources on the planet. Combined with sunlight, they sustain our very existence. Human activities have had and continue to have a damaging effect on these valuable resources. Our land is literally blowing away. Water and soils are becoming more saline. Desertification is increasing.

Soil erosion is one of the most severe environmental problems in the world. Over the past 40 years, approximately 30 percent of the total world’s cropland has been abandoned due to wind and water erosion (Pimentel 2000). Soil erosion has a negative impact on food production by reducing yield. While attitudes and awareness of the problems have improved significantly over the past 10 years, soil is still being eroded at a phenomenal rate.

According to Pimentel (2000), African soil has turned up in Florida and Chinese soil has been blown to Hawaii. Figures 3 and 4 show how this is possible. They also illustrate how the land management activities of one country can have a negative impact on others. This is not confined to Africa; it is a global problem.

On a global scale, Asia has the highest proportion of degraded forestland. Africa and Latin America appear to have the highest proportion of degraded agricultural land (Scherr and Yadav 1997). Soil erosion will create serious production problems in southeast Nigeria, Haiti, the Himalayan foothills, southern China, Southeast Asia and Central America. Deforestation will threaten critical habitats in Southeast Asia, Madagascar, the Amazon the Atlantic lowland of central America, the Pacific rain forest of Colombia and Ecuador, and the Chaco region of Lain America (Scherr and Yadav 1997).

In northern China, grassland soils are being severely degraded under cultivation and grazing. In this region, 59 percent of organic carbon has been lost within 30–50 years of cultivation (Wu and Tiessen 2002). Studies by Lal (1995) estimate that by 2020, soil erosion could reduce yield by 16.5 percent in Africa and 14.5 percent in Sub-Saharan Africa.

Figure 3. Cape Verde Islands in the Atlantic Ocean with a massive wall of Sahara Desert dust approaching from the east. Image acquired by NASA Moderate Resolution Imaging Spectroradiometer (MODIS), 3 February 2004.

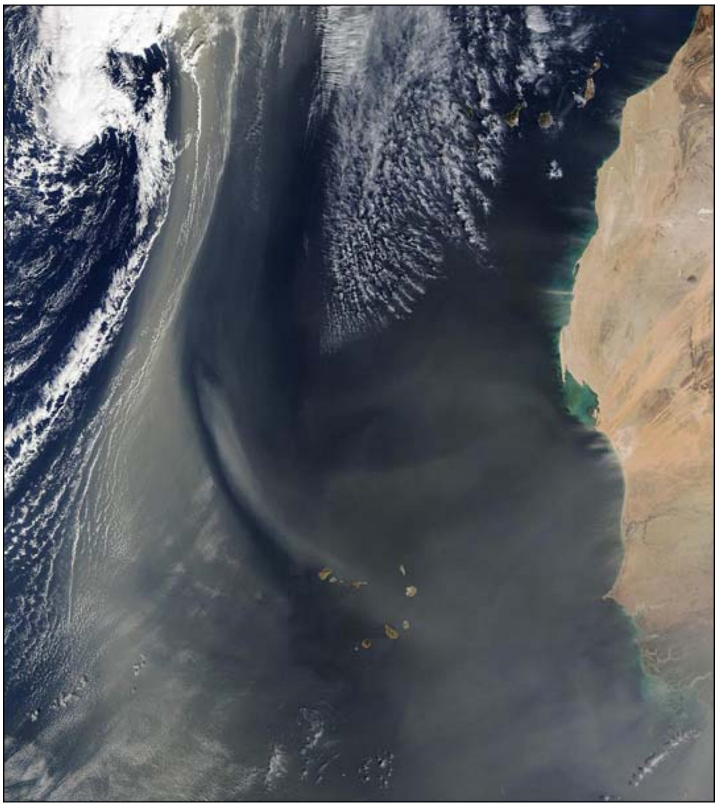

Figure 4. Saharan dust over the Atlantic Ocean.

Water: a global perspective

Water is essential for all agriculture. Accordingly, agriculture is by far the largest user of water, claiming almost 70 percent of the total amount withdrawn globally (FAO 2002). The average person will consume about 4 litres of water a day. However, it can take up to 5,000 litres of water to produce that person's daily food (FAO 2003). It takes 1,000 litres of water to produce a kilogram of grain. It requires 100,000 litres of water to produce 1 kg of meat requires, including water that goes into the crops and grains that are used to feed the animal (Pimentel 2000). It takes about 0.36 megalitres per head to supply a kilo of cereal per head per year. Table 1 demonstrates that in Asia, this represents 10 percent of water availability in 2000.

Table 1. Per capita water availability in megalitres by region, 1950–2000

Region	1950	1960	1970	1980	2000
Africa	20.6	16.5	12.7	9.4	5.1
Asia	9.6	7.9	6.1	5.1	3.3
Latin America	105.2	80.2	61.7	48.8	28.3
Europe	5.9	5.4	4.9	4.4	4.1
North America	37.2	30.2	25.2	21.3	17.5

Source: FAO (1995) page 355

Table 1 shows that the combined effect of population and economic growth will exert even greater pressures on freshwater supplies. The pressures on water will be greater than on land resources (FAO 1995). Although Latin America is well endowed with water, many countries, particularly in Africa and Asia, are already closer to their water supply limits than their land limits. The need to increase agricultural production will accentuate pressures on water resources. With world population increasing, it is imperative that water is used both efficiently and fairly on a global scale. Many believe that unless properly managed, lack of access to freshwater for agriculture could emerge as the key constraint to global food production (Kinjne *et al.* undated).

An FAO study of 93 developing countries indicates that some water-scarce nations are already withdrawing water supplies faster than they can be renewed. Ten countries are in a critical state, meaning that agriculture accounts for more than 40 percent of total withdrawals of renewable water resources (FAO 2002). Rectifying this situation will require significant changes to the way in which water is used. Improved farming techniques and greater efficiency in water use are the keys to food security for a growing world population (FAO 2002).

Water disasters

Of the many examples of environmental disasters associated with the over use of freshwater, the Aral Sea in central Asia would have to be one of the worst. Millions of cubic metres of water were diverted for cotton irrigation, resulting in a 16-metre drop in sea level over 30 years (FAO 2002). Fish catches that once totalled 44,000 tonnes per year dropped to zero. Toxic salts from the dry seabed deposited on surrounding farmland, killing crops (FAO 2002). While this is an extreme example, it illustrates how carefully we need to manage freshwater resources. The pressure on both surface and groundwater is increasing. Unfortunately, the extraction of water from groundwater is rarely integrated with the extraction of surface water. In far too many instances around the globe, surface and groundwater are managed as separate entities, yet in most catchments, they are strongly linked and affect each other as well as the wetlands, lakes, estuaries and near-shore marine environments. Rivers and their groundwater systems are living entities that need water flow regimes to maintain ecological functioning and thus water quality.

Most of the water management disasters derive from a failure to take a whole-of-system approach to hydrology and its management. This provides great opportunities to vastly improve the management of water resources.

Irrigation

Irrigation is fundamental to food production. Sixteen percent of the world's cropland in under irrigation (Kendall and Pimentel 1994). This land produces two and a half times more per hectare than non-irrigated land, however, vast amounts of water are needed to sustain this industry (Kendall and Pimentel 1994). Irrigated land is subjected to water logging and increasing salinisation due to poor irrigation practices. There are serious salinisation problems in India, Pakistan, Egypt Mexico, Australia and the United States irrigation (Kendall and Pimentel 1994). These areas are naturally high in salt, and irrigation methods add to these levels. The result is excessively high salt levels that also increase salt levels in rivers and water tributaries. Water for irrigation can be obtained from aquifers, and in many of these aquifers the rate of extraction exceeds the rate of recharge. Ground water levels in China are falling as much as 1 m per year in the major agricultural growing regions of the North China Plain (Postel 1990). In India, ground water levels are falling 2.5–3 m per year (Kendall and Pimentel 1994)**.**

Salinisation will be a major threat in the irrigation systems of the Indus, Tigris and Euphrates River basins, in northeastern Thailand and China, the Nile delta, in northern Mexico and in the Andean highlands (Scherr and Yadav 1997). In addition, drainage from irrigation often results in loss of water quality, the spread of water-related diseases and soil degradation through water logging (FAO 2003).

Global challenge to feed the world and maintain the natural resource

Soil erosion has a devastating impact on food production, especially considering that land masses produce more than 99 percent of the world's food, while less than 1 percent of food is obtained from the oceans and other aquatic habitats (Pimentel 2000). The Global Land Assessment of Degradation estimates that nearly 2 billion hectares worldwide have been degraded since mid-century, that is, 22 percent of all cropland, pasture, forest and woodland (Scherr and Yadav 1997). The figures for cropland alone are even worse. There are nearly 1.5 billion hectares in cropland worldwide, of which about 38 percent are degraded to some degree (Scherr and Yadav 1997). The cumulative productivity loss for cropland from soil degradation over the past 50 years is estimated to be about 13 percent (Scherr and Yadav 1997)

Of the 6 billion people on earth, 3 billion are malnourished (WHO 1996). The FAO (2003) reports that global food production will need to increase by 60 percent to close nutrition gaps, cope with an increase in population growth and accommodate changes in diets over the next three decades.

With increasing soil erosion, land degradation and water scarcity, will it ever be possible to feed the world?

Global wellbeing of ecosystems and nations

A useful assessment of the global wellbeing of ecosystems and nations is provided by the Wellbeing of Nations, which surveys 180 countries then ranks them according to measures of human development and environmental conservation.

This method of assessing sustainability provides a systematic and transparent way of combining the indicators into a Human Wellbeing Index, Ecosystem Wellbeing Index, Wellbeing Index, and Wellbeing/Stress Index (the ratio of human wellbeing to ecosystem stress). Together, these four indices provide a measurement of sustainable development.

The Ecosystem Wellbeing Index (EWI) is a broad measure of the state of the environment. The 51 indicators used to generate this index include:

- **Land**. Conservation and the diversity of natural ecosystems and the quality of ecosystems that are developed.
- **Water.** Water quality of drainage basins and water withdrawal as a percentage of the national supply from precipitation.
- **Air.** Greenhouse gas emission and city air quality.
- **Species and genes.** Conservation of plants, animals, birds, amphibians and reptiles
- **Resource use.** The amount of energy a country consumes, and the demands its agriculture, fishing and timber sectors place on resources.

(Source: Prescott-Allen 2001)

The EWI as expressed in Figure 5 shows that environmental degradation is widespread. Countries with a poor or base EWI cover almost half the planet (48 percent). No country has a good ecosystem wellbeing index. Most countries could raise their EWI by restoring and maintaining habitats, expanding protected areas, conserving agricultural diversity, and improving water quality. Industrialised countries need to reduce greenhouse gas emissions. (Prescott-Allen 2001)

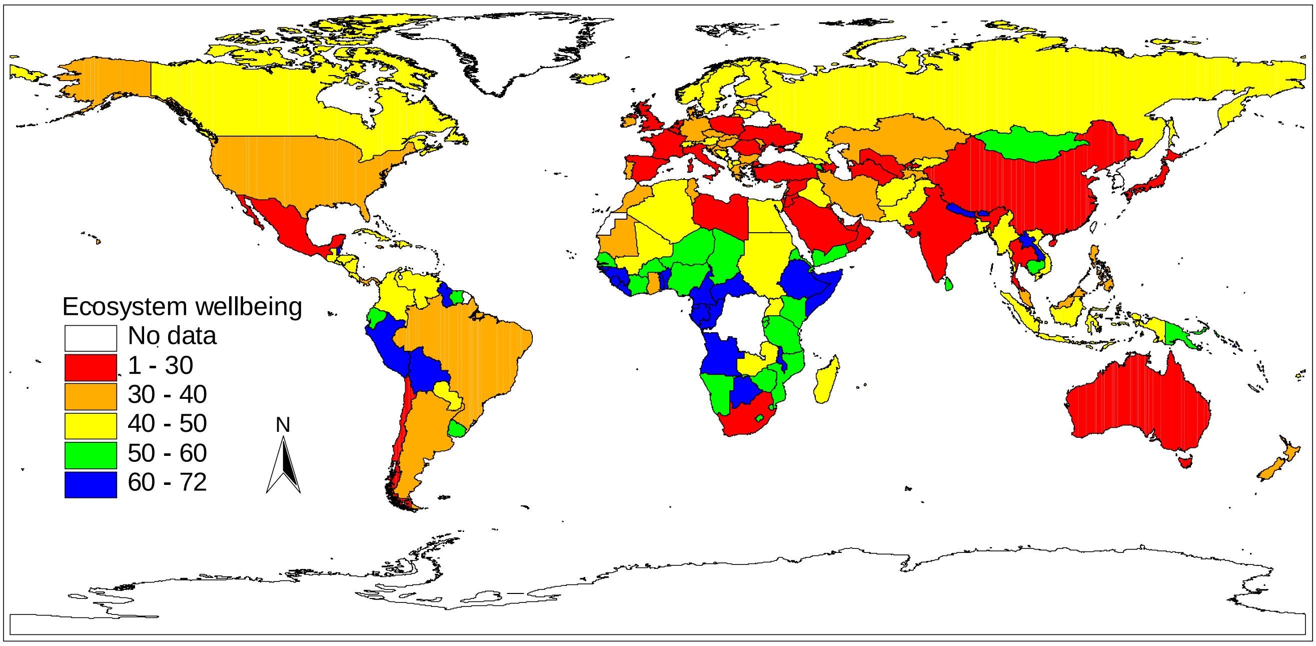

Figure 5. Ecosystem Wellbeing Index

The Wellbeing Index combines the Human Wellbeing Index and Ecosystem Wellbeing Index into a single index that shows how well societies combine human and ecosystem wellbeing and hence how close they are to sustainability. Table 2 lists the five top and bottom countries on the index and selected countries in between.

Table 2. Wellbeing Index ranking of selected countries

Rank	Country	Wellbeing Index
1	Sweden	64
2	Finland	62.5
3	Norway	62.5
4	Iceland	61.5
5	Austria	61
18	Australia	53.5
27	United States	52
33	United Kingdom	51.5
144	Rwanda	34.5
160	China	32
167	Pakistan	31
176	Saudi Arabia	27
177	Uganda	27
178	Afghanistan	27
179	Syrian Arab Republic	26.5
180	Iraq	25

Adapted from (Prescott-Allen 2001).

While Sweden is ranked at the top of the Wellbeing Index and enjoys the highest standard of living, it still needs to raise its standards in the ecosystem index. This study also shows that countries that have a similar standard of living can have significantly different levels of impact on the environment.

The Wellbeing of Nations represents a paradigm change from a world where traditional measures are based on Gross Domestic Product to one that gives equal weight to people and the ecosystem. This marks significant progress, given that human development is intimately entwined with the environment, and as ecosystems sustain life on earth, a high level of ecosystem wellbeing is essential.

Future options for society

Kendall and Pimentel (1994) offer three scenarios for possible outcomes to the year 2050: business as usual, pessimistic and optimistic. Under business as usual, the world's population is estimated to be 10 billion, and land and water degradation continues to make it increasingly difficult to produce food. Africa China and India will face severe problems expanding their food supply to feed their inhabitants. The population of these three regions will account for half the world's population. In the pessimistic scenario, the world population is 13 billion and there is little hope of providing adequate food for the majority of the population. The optimistic scenario is based on a stable population of 7.8 billion and would require current grain production to double. Irrigation and grain production areas would need to be expanded by 20 percent and fertiliser inputs by 450 percent. Soil and water conservation programs would have to be implemented to halt soil erosion. The developed world would help finance these changes.

Securing future food and natural resources

Conservation farming is being taken up by an increasing number of farmers around the world. The FAO (2002a) estimates that conservation farming is undertaken on about 58 million hectares of land (see Table 3). Conservation farming is a good news story: it reduces soil erosion and water loss, protects soil biology and structure, increases yields, and reduces fuel consumption and chemical inputs.

Table 3. Countries and area using conservation farming techniques.

Country	Zero tillage 1999–2000 (ha)
USA	19 750 000
Brazil	13 470 000
Argentina	9 250 000
Australia	8 640 000
Canada	4 080 000
Paraguay	800 000
Mexico	650 000
Bolivia	200 000
Chile	96 000
Colombia	70 000
Uruguay	50 000
Venezuela	50 000
Others	1 000 000
Total	58 106 000

(FAO 2002a)

Farming can be sustainable. Farming practices can incorporate many methods that do not have a negative impact on land and water resources. For example, in Africa, Asia and Latin America, diversification into perennial crops is protecting soils; in Syria, Jordan, Southern Africa, Mexico and Argentina, dryland range rehabilitation schemes are also showing positive results (Scherr and Yadav 1997). An effective response to land degradation also calls for improving both the incentives for farmers to care for their land and their access to knowledge (Scherr and Yadav 1997).

The way forward for water

Sound water policies are needed to prevent catastrophes such as the Aral basin. These policies must incorporate environmental issues while maintaining equitable access to water resources. The FAO (2002) suggests that water access could be improved by treating it as an economic commodity as well as a social right. A suitable pricing policy ensures that watering is economically expensive is probably one of the best incentives to conserve water. These policies must be implemented at all levels of government: international, national and local.

Sweeping irrigation reforms in the 1990s have led to a considerable transfer of responsibility to local water-user associations and a shift to demand-driven management strategies. However, there is a long way to go.

Improving irrigation and water productivity

There is available technology for increasing irrigation efficiency. One example is drip irrigation systems, but they are expensive and many small-scale farmers do not have the resources to purchase them. An FAO drip irrigation project in Cape Verde increased the island's horticultural production from 5,700 tonnes in 1991 to 17,000 tonnes in 1999 (FAO 2003a). The productivity of water used in agriculture has increased by at least 100 percent between 1961 and 2001 (FAO 2003b), due mainly to improved crop yields. Irrigated rice yields have doubled, rain-fed wheat yields rose by 160 percent in the same period, and there was little variation in water consumption per kilo of output (FAO 2003b).

The way forward for feeding the world
The Consultative Group on International Agricultural Research (CGIAR) Challenge Program on Water and Food aims to improve water productivity for food production in ways that are gender equitable, environmentally sustainable and assist the poor. The intention is to achieve food security while reducing water requirements in agriculture.

The program's themes include:
- improving the efficiency of water use in agriculture, via increased crop water productivity
- managing upland watersheds for multiple functions
- managing aquatic ecosystems and wetlands (including biodiversity and ecosystem function), with particular emphasis on both aquaculture and capture fisheries
- policy and institutional aspects of water management
- integrating water resources management.

In outlining what *could* be done, Scherr and Yadav (1997) have identified strategies directed at the sustainable use of agricultural land. These include increasing research and technology for land management; and distributing and promoting land-improvement technology by, for example, building up soil organic matter and planting trees. Other strategies include encouraging long-term land improvements by securing property rights and rights of access to natural resources; and developing planning systems for sustainable land use that involve key resource user groups.

The next 30 years will certainly throw up new challenges. As world population grows to an estimated 8,300 million in 2030, agriculture must respond to changing patterns of demand for food, combat food insecurity and poverty in rural areas and compete for scarce water with other users (FAO 2003).

Some learning from Australia
As a nation and at the community level, Australians are increasingly recognising the seriousness of the problem and the need to address it. However, two critical issues are impeding our progress:

- In natural systems there are frequently long lag times before the benefits of improved land and water management are observed. These lags may amount to decades in the case of sediment and groundwater movement. Sometimes we have to accept that such slow responses mean things could get worse before they improve.

- Complex interactions mean that any action in a catchment may not have the anticipated result downstream. For example, sediments removed by erosion may move spasmodically through a catchment, being entrained in flows for only short periods, while frequently being held in temporary storages. What happens in each part of a catchment cannot simply be added to the other parts to generate a whole catchment picture. As a result, we do not know how effective on-farm management will be in improving water quality in large catchments.

Australia's knowledge and skills in the natural resource sciences are among the best in the world (e.g. Prosser et al. 2001). The continuing success of many rural industries is largely the result of genetic improvement programs, and improved production and processing practices. Yields and quality of many crops and animal products have been maintained or improved sufficiently to offset, at least partially, the continued decreases in price paid for many products in international markets. In addition, our knowledge of natural resources and ecosystems has reached a very high level, as has our ability to manage them in many areas. Increasingly, however, this knowledge is indicating that we have been affecting many of our natural systems in ways that are reducing their ability to cope with the effects of farming, and that most of our practices are not sustainable.

Urgent search for new farming systems and land-use patterns

Solutions to environmental and natural resource issues require institutional, structural and social change as well as new scientific knowledge and strong economic drivers. It is a key requirement that people from all sectors of the community need to be involved with scientists from the earliest stages of a program, involving planning, research implementation, monitoring and evaluation. Scientific and technological innovation both on farm and in laboratory will play a fundamental and increasing role in the development of sustainable farming. However, innovation will have a much greater impact if it becomes a tool within rural society, and is not used to set the agenda in isolation from the rural community.

Development of ecologically sustainable farming systems that are profitable is a very difficult problem, both scientifically and socially (Williams 2001; Williams and Gascoigne 2003). Were this not so, we would not be in our present predicament. It is most misleading to assert or assume that our current knowledge base is sufficient and that ecologically sustainable land use is possible by simply applying existing knowledge. Current information must be applied, but it must also be recognised that many of the current management issues are the result of failure to develop farming systems within an ecological framework that is integrated with the processes occurring in the landscape. Few farming systems are able to control the cause of land degradation while generating a farm income that can sustain rural communities. The search for farming systems and land use patterns that do not harm our environment is urgent.

Integrated approaches to natural resource management and land use

Faced with the evidence and increasing public concern about damage to our natural resources from current patterns and land-use practice, government, community, and industry and scientists responded by seeking solutions and innovation.

One important insight was that the problems required a multi-faceted approach. Fixing one problem while causing another is not progress. Relying on simple technical fixes would not do. The solutions required a combination of scientific knowledge with people processes and understanding. A mix of scientific pointers to the problem, people processes and drivers with capacity to predict was sought.

In Australia, this came about with the evolution of these ideas into what became known as Integrated Catchment Management (ICM), Total Catchment Management (TCM) and most recently, Whole Catchment Planning (WCP). Integrated approaches to resource management and land use emerged in the 1980s in Australia against a background of increasing pressure on natural resources, growing public awareness of natural resource issues, and increasing community expectations of influencing decisions about land use. At the broadest level, integrated resource management procedures involve the integration of environmental and economic considerations at management, planning and policy levels, which is argued to be an effective means of implementing the principle of sustainable development

Catchment care programs, including ICM and its close relations, total catchment management (TCM) and whole catchment planning (WCP), have been adopted as policy by a number of Australian states for catchments where there are conflicting and competing resource use problems and/or multiple institutional responsibilities. These programs aim to achieve balanced and sustained use of land, water, vegetation, and other biological resources through the coordinated and cooperative actions of individuals, community groups, industry, and government at its various levels. The argued need for ICM is continuing degradation of land, water and related resources; conflicting government policies; different agencies with statutory responsibilities leading to non-complementary programs; and increasing public expectations for involvement in decision-making.

They are whole-of-government approaches to natural resource management on a catchment-wide basis. In principle, a whole-of-system approach is taken where it is recognised that rivers are linked to catchments, usually through an appreciation of the integrating nature of the water cycle. That is, the linkage between land use—particularly irrigation on the surface—and groundwater water flows within the catchment to river, wetland, and estuary, taking into consideration the irrigation or urban extractions and returns. This is set out in Figure 6.

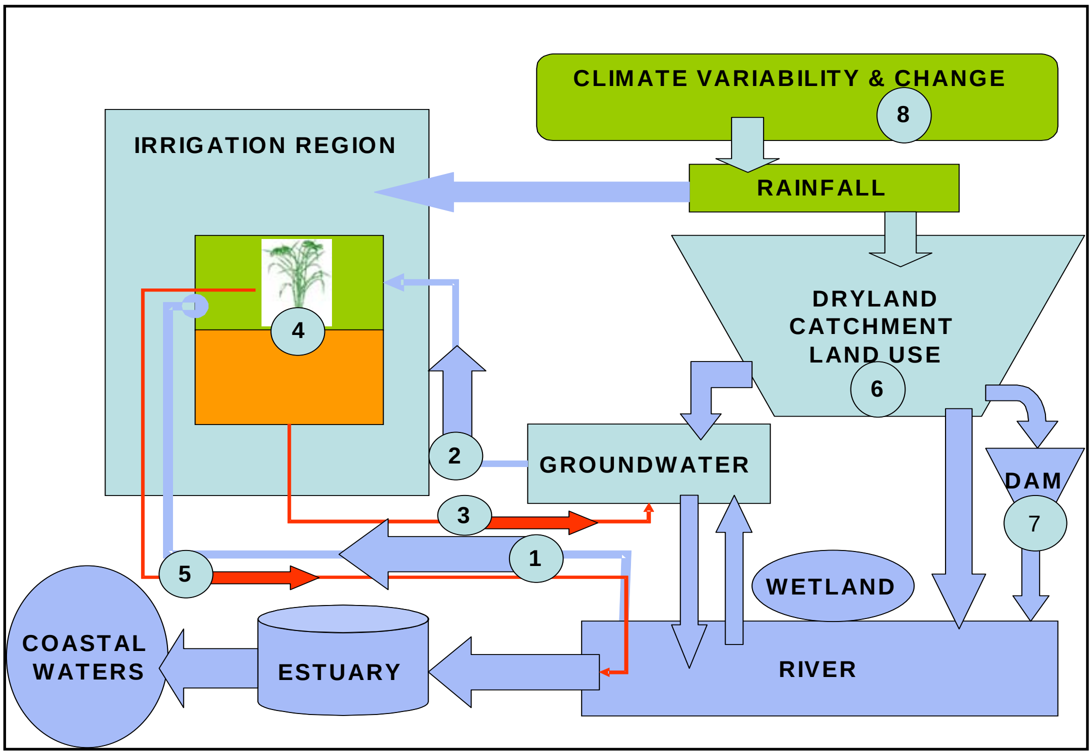

Figure 6. An example of a whole-of-system approach to river, catchment, irrigation landscape.

The whole-of-system approach must do more than integrate the biophysical components of the systems; it is central to ICM that it engage with the interaction and processes in the social, institutional, economic and legal components of all that is involved in activity associated with the river and the catchment management. This is hard stuff. Progress has been slow and there has been much learning but few unblemished successes to record: in terms of human learning, it is still early days. Yet it is an innovation that has the ingredients for ultimate success in the management by people, governments and industry of their precious water, soil and biodiversity.

Landcare: a 'true blue' response

Australia has a long history of governments working with individual farmers and small farmer groups in soil conservation projects. In the 1970s and 1980s, however, Australia's environmental consciousness became more highly developed and other legacies of the past, such as salinity and loss of biodiversity, became more noticeable. What has changed is the approach to managing group projects. The initial catchment conservation programs were focussed on controlling soil erosion, and initiated and run at a government agency level. Community-owned, natural resource management farming groups began to form in most states, but particularly in Western Australia and Victoria, in the early 1980s.

Although other states also had voluntary community-based conservation groups, a national focus did not develop until late 1989, when the Decade of Landcare was announced by the Federal Government. Support funding was also allocated, administered through the National Landcare Program (NLP). The Federal Landcare initiatives had a major input from a joint submission by the National Farmers Federation and the Australian Conservation Foundation. This 'bottom-up' approach has had considerable success in terms of the number of farmers and farms now involved, compared with the initial agency-led programs.

From its early beginnings, Landcare is now a broad movement comprising over 4,000 Landcare groups Australia-wide, with 40 percent of farmers as members and influencing at least a further 35 percent of farmers.

The effectiveness of Landcare can be measure in terms of communication—raising awareness, changing attitudes and behaviour—and in improving NRM outcomes.

- **Communication**

Landcare has played a major role in raising awareness of NRM issues, and has been an important vehicle for transferring information, generating knowledge, enhancing skills and confidence amongst farmers and the community on sustainable production and better management practices. This has provided the foundation for adoption of changed farming practices, and improved profitability and NRM outcomes.

The landcare movement has been valuable in generating and maintaining social cohesion, particularly in the more remote communities. It is providing information to landholders on production aspects of sustainable farming, and has been the entry point for landholders to broaden their approach to whole-farm management, including consideration of the off-farm impacts of their farming operations.

- **Improving NRM outcomes**

Landcare has been a major foundation for the adoption of sustainable land use management practices, such as no-till, trash-blanketing, and sustainable grazing. Improvements in the condition of land, water and vegetation resources have been discerned at the farm and local level, but not at the broader catchment or regional scale. Examples include lessened impact of the drought, reduced drift, better vegetation cover, better soil condition, and less in-stream turbidity. However, Landcare has not been the vehicle for implementing regional land-use change, although it is successful in changing land management and resource condition at farm and neighbourhood level. Landcare activities need to link more to wider catchment and regional outcomes. Landcare also needs to use more market-based signals and economic information as a way to stimulate engagement with non-participant landholders.

Reforming Australia’s water resources: a courageous response

Australians consume more than 24,000 gigalitres of water a year. More than 70 percent of this is used for irrigation while a further 21 percent goes to urban and industrial uses. The rest is used in other rural activities.

Water is crucial to Australia’s natural and economic wealth. It is the basis of one of our largest industries, accounting for about A$90 billion of infrastructure investment and contributing over A$7 billion to annual revenues through irrigated agricultural production (about 25 percent of Australia’s agricultural production).

Many of Australia’s rivers have highly variable flows. Droughts and floods are common. The flow variations have led us to develop our rivers and groundwater resources extensively for irrigated agriculture and domestic water supplies. Indeed, our rivers and groundwater resources were vital in Australia’s early settlement and development, often determining the location and viability of population centres and areas of agricultural production.

Inefficient water use has created problems of national significance, such as salinity in rivers and soil. All levels of governments recognised that coordinated action was needed to stop widespread degradation of Australia’s natural resources. Under the Australian Constitution, water resource management lies with state and territorial jurisdictions. However, river systems and catchments cross state and territory borders and water reform issues such as water trading and environmental flows concern all jurisdictions and require a national approach.

In 1994, the Council of Australian Governments (COAG) agreed to establish a national Water Reform Framework to address the need for the sustainable management of Australia’s water resources. The framework was formulated in response to considerable concern about the state of many of Australia’s river systems and recognition that an important part of the solution lay in significant policy and institutional change.

The major elements of the COAG Water Reform Framework are: water pricing based on the principle of full cost recovery; the establishment of clearly specified water entitlements; allocations to the environment, first by way of a cap on water extractions from the Murray-Darling Basin; institutional reform; public consultation and education; and research.

In 2003, Australians were confronted with a most serious drought. This had a profound impact on our water supplies at a time in our history when national awareness converged with an imaginative policy and knowledge foundation built by community, government and industry since 1994 and the historic decision to cap water extraction from the Murray-Darling Basin. The forces for change and reform of water policy seemed aligned. The Wentworth Group of concerned scientists published *A Blueprint for a National Water Plan* as part of the national debate. This, with all of COAG's previous policy work, drove processes that led to what may become one of the most innovative water reform agendas in the world: COAG's National Water Reform Initiative, which aims to achieve the efficient and sustainable use of Australia's water resources.

Main elements of water reforms

The Australian water reform framework recognises the unique characteristics of Australia's water resources and their contribution to the economic, social and environmental life of Australia. The reforms comprise diverse but interrelated requirements to generate an economically viable and environmentally sustainable urban and rural water industry:

- All water pricing is to be based on the principles of consumption-based pricing, full cost recovery and transparency of cross-subsidies, with removal of cross-subsidies not consistent with efficient and effective service, use and provision. For urban water services, charges include an access and usage component. For metropolitan bulk-water suppliers, charges are on a volumetric basis to recover all costs.
- Any future new investment in irrigation schemes, or extensions to existing schemes, is to be undertaken only after appraisal indicates it is economically viable and ecologically sustainable.
- State and territory governments are to implement comprehensive systems of water allocations or entitlements, which are to be backed by the separation of water property rights from land and include clear specification of entitlements in terms of ownership, volume, reliability, transferability and, if appropriate, quality.
- The formal determination of water allocations or entitlements includes allocations for the environment as a legitimate user of water.
- Trading (including across state and territory borders) of water allocations and entitlements is within the social or physical and ecological constraints of catchments.

There is an integrated catchment management approach to water resources. It incorporates the following elements:

- as far as possible, separating resource management and regulatory roles of government from water service provision
- greater local-level responsibility for water resource management
- greater public education about water use and consultation in implementing water reforms
- research into water-use efficiency technologies and related areas.

If Australia is to manage its water resources on a sustainable basis, there are two factors essential factors. The first is the principles behind the development of water markets (the definition of property rights to water, and the separation of land and water assets). The second is an assessment and approval process by Australian governments to ensure that any negative environmental impacts, such as salinity and deteriorating water quality, are properly accounted for with water trading and pricing arrangements.

Conclusions

Global food and fibre production to support human society is producing commodities with ever-declining terms of trade and at significant cost to the environment, as evidenced by extensive losses of species and changes in ecosystem processes, resulting in the increasing degradation of our land and water resources. Although many adaptations have been made, the agricultural management practices over large regions of the globe are not sustainable in terms of energy, water, nutrient and carbon cycles within the agro-ecosystems and their links to landscape processes. At a global level, the gap between productivity gains, based on innovative science and technology, and productivity losses due to damage to the natural resource base, appears to be narrowing quite rapidly. It is an urgent imperative that we conserve the land and water resource base for society. A response to the resource damage is to put in place the foundation arrangements necessary to produce different agricultural systems for the globe—ones that are more in harmony with their environment and able to support viable rural communities. Leaking of carbon, water, nutrients and sediments has caused loss of native species and changes in ecosystem processes. Innovative and inclusive approaches to remediation are required to build ecologically sustainable landscapes that can capture this leakage and turn it into wealth creating food and fibre products.

Ecosystems produce goods, which are the products we harvest from eco-systems, and services such as regulation of the hydrological cycle, maintenance of nutrient cycling, removal of carbon dioxide, production of oxygen, disposal of wastes, and pollination. We need to develop the notion of valuing and marketing ecosystem services.

The challenges are scientifically demanding. Partnerships between governments, businesses, community sectors and scientists are needed in regional development and there is also need for a mosaic of farming and land uses that do no further harm to the environment (Williams and Saunders 2003). The search for sustainable landscapes will be incremental and based on an adaptive management cycle of research, innovation, monitoring, reporting and revision. The current knowledge base is insufficient to the requirements. There is a real urgency about the development of farming systems and land use that will not harm the environment.

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