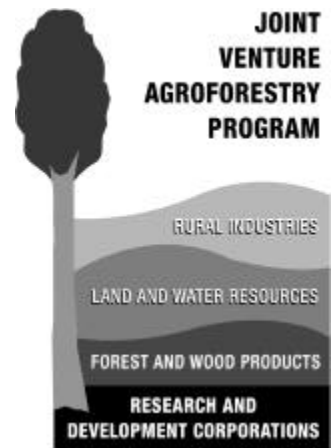




Determining the Effectiveness of Vegetation Management Programs

Measures and Methodologies
- Literature Review

RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program
(supported by the Natural Heritage Trust and the Murray Darling Basin Commission)
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Foreword

Vegetation management has been used as a tool in many land, water, conservation and agricultural improvement projects. This literature review was initiated to survey current knowledge of the biological, physical and socio-economic processes occurring in these projects so that useful indicators linking actions to final outcomes could be identified more easily.

This wide ranging review includes research on salinity, soil conservation, water quality, biodiversity, wood production, crop yields, infrastructure damage and carbon sequestration. It also encompasses the success or otherwise of programs directed at changing people's behaviour in relation to conservation programs and suggests areas in need of further research.

The report was initiated as part of a consultancy concerned with *Measures and methodologies to determine the effectiveness of vegetation management programs*. The consultant team consisted of the Centre for International Economics (CIE) and the CSIRO, and was funded by Environment Australia (EA), through Bushcare, a Natural Heritage Trust program, and the RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program.

RIRDC's involvement in this project and in the Joint Venture Agroforestry Program, is part of the Corporation's Agroforestry and Farm Forestry R&D Program which aims to foster integration of sustainable and productive agroforestry within Australian farming systems.

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Peter Core

Managing Director

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Executive Summary

Many research and management projects involving vegetation management have been carried out in Australia. The RIRDC/LWWRDC/FWPRDC Joint Venture Agroforestry Program has been supporting R&D into agroforestry and farm forestry since 1993. The guiding objective of the program is *to integrate sustainable and productive agroforestry within Australian farming systems*. More recently, activity in the area of integrating vegetation into Australian farming systems has increased under the Natural Heritage Trust (NHT) initiative, particularly through the Bushcare and Farm Forestry Programs. This literature review aims to describe the results of research work on vegetation and its impacts on the biological and physical environment, as well as production and socio-economic outcomes.

In keeping with the key outcome areas of the Natural Heritage Trust, the impacts of these projects are reported here against four areas: environment, sustainable production, people, integration and institutions. In each area, a framework linking the processes to outcomes, with relevant indicators for monitoring is presented.

Biophysical processes-conservation outcomes

Firstly, the review investigates **biophysical processes for attaining conservation outcomes**, to examine evidence as to whether on ground actions, such as establishing vegetation and/or protecting remnant vegetation, produce desired outcomes, such as reducing watertables and salinity, improving soil conservation and water quality, and protecting biodiversity. There is considerable uncertainty about the links between on-ground actions and conservation outcomes. Further investigation of the biophysical processes for dryland salinity control, in particular, is required.

Tree planting in recharge locations can contribute to the control of dryland salinity. Trees use more water, from deeper in the soil profile, throughout the year compared to annual crops and pastures, reducing the amount of water reaching the watertable. Whether this effect is significant enough to halt, or reverse, the process of salinisation depends on the extent of the area that is planted to trees, and the location in which they are planted. Tree planting in discharge areas is not a solution to dryland salinity, but rather a ‘band-aid’ approach to the problem. Modelling may allow predictions about how long it will take for revegetation to exert control over rising watertables. However, it is probable that the rate of the response is dependent on the area that is planted, the location planted, the hydro-geology of the catchment and the species planted.

Vegetation can be effective in reducing wind and water erosion of soils. Benefits are maximised through a combination of trees, shrubs and ground cover plants, as well as litter, to protect the soil surface from raindrop splash and to obstruct overland flow. Wind erosion can be reduced by shelter belts of appropriate layout, height and width.

Vegetation has an important role to play in improving water quality. Riparian vegetation is critical to the efficient functioning of aquatic ecosystems. Native species are most valuable as they provide a consistent habitat for aquatic flora and fauna throughout the year. Vegetation may be of limited value in buffering streams and rivers from point source

pollution, but can be effective in reducing diffuse source pollution, through obstructing and filtering overland flow. Groundcovers such as grasses, sedges and rushes are particularly effective. There is considerable potential for plantations irrigated with effluents to reduce the pollution contributed to inland rivers by wastewater.

The review of research associated with biodiversity conservation reveals that protection of existing habitat, and increasing the area of potential habitat, are critical to conserving biodiversity. Buffer zones are highly effective in protecting habitat from abiotic sources of disturbance, but less so from biotic sources. There is uncertainty about the contribution and value of revegetated corridors/links to the conservation of biodiversity. The biodiversity benefits of plantations are likely to be minimal where exotic species such as *Pinus radiata* are established as a monoculture. The benefits may be very small if the tree crop is managed for maximum production of wood by using intensive inputs such as herbicides, fertilizers or pesticides.

Biophysical Processes - Sustainable Production

The review found evidence that on-ground actions involving vegetation and conservation outcomes can improve agricultural productivity, but that quantification of the effects is difficult.

Despite the widespread use of contour banks and grassed waterways, and some revegetation, there are no quick-fix solutions to many soil degradation problems. Solutions are often complex, need to be ecologically based and may take many years to be effective.

Trees, shrubs and grasses that are effective in controlling erosion are likely to have a positive benefit on production. This is because effective erosion control can not only reduce the amount of land taken out of production, but may also reduce declining production on remaining land, through conservation of ecosystem resources such as soil and nutrients. Trees have a role in the provision of shelter to plants and animals. In dryland cropping areas, reduction in evaporation appears to be the most important factor. Moisture that is conserved in the sheltered zone can be used by plants later in the growing season, particularly during the critical times of flowering and grain filling. Shelter may improve plant growth through the amelioration of microclimate (primarily reduced windspeeds and warmer temperatures) and by more efficient plant use of water. Shade and shelter have beneficial effects on stock by reducing environmental stress from heat and cold. Indications are that productivity from pasture and grazing stock increase with the provision of cover until about one-third of the farm is covered by woodland. A similar situation has been described for many crops. The degree to which an economic return will result from the provision of shade and shelter will depend on the climate and topography, the species and age of plant or animal

Remnant native vegetation and revegetation can provide habitat for birds and insects that prey on insects that are agricultural pests. Without these native predators, the average level of attack on agriculture by insects and the frequency of outbreaks may be higher. At present little provision is made on farmland to provide habitat for these predators. It may be economically beneficial for farmers to maintain their remnant vegetation and to revegetate to encourage insectivorous birds and predatory invertebrates in the same way that they manage their pastures. However, a potential disadvantage is that revegetated areas and remnant vegetation also provide habitat for exotic pests such as rabbits and foxes.

A review was undertaken of the potential for tree-planting for commercial production. Trees planted for wood production generally require an existing market in order to be economically viable. Species need to be carefully selected on the basis of site capability and marketability. Many of the existing commercial species are well suited to farm forestry as they pose less of a problem to farmers who usually have trouble in guaranteeing continuity of supply. Careful and timely silvicultural management is crucial to the production of high quality wood products.

Non-wood forest products which are significant in Australia include: essential oils; honey and pollen production; wildflowers and tree foliage; broombrush; sandalwood; seed; Christmas trees; drugs; tannins; gums; resins; cane; and charcoal.

The issue of carbon sequestration is addressed as an associated potential benefit of revegetation management and establishment activities. Although increasing the amount of vegetation is not a complete solution to the problems posed by global climate change, it may provide the buffering capacity needed to develop responses that deal fundamentally with release to the atmosphere of fossil carbon. Any attempt to measure the effectiveness of trees in sequestering CO₂ will need to take into account the rotation length and growth rate of the vegetation and the purpose of the tree planting.

Socio-economic Impacts

The review considers the socio-economic processes associated with vegetation programs, to determine what evidence there is to link project outputs involving people and institutions, such as training or regional land management plans, with on-ground actions by land managers.

It was found that links between programs or projects aimed at people and communities, and changes in actual behaviour and adoption of good vegetation management practices are tenuous. In general, however, there is some evidence that participation in training and landcare groups does lead to the adoption of more sustainable management practices.

Much more needs to be known about what makes people change their behaviour and protect or establish vegetation. Yet this is a critical link in the overall success or otherwise of the programs. It is important to identify and understand the impediments to adoption of particular vegetation activities, both commercial and non-commercial.

There is strong evidence that there have been significant changes in attitudes of farmers towards native vegetation management on their farms over the past decade. There is also some evidence that participation by farmers in training and Landcare groups does lead to adoption of more sustainable management practices. In the same vein, a major impediment to increasing native vegetation on farms is the lack of information by farmers on appropriate species to plant, locations, biodiversity values and other aspects of native vegetation management for most effective results.

The report then assesses a range of tools to assist in putting a value on project outcomes to farmers and the broader community.

Where physical relationships can be identified, valuing final outcomes which have a market value presents few difficulties. The real difficulties lie in valuing outcomes which do not have market values.

Conservation outcomes have both use and non-use values, while sustainable production outcomes have use values only. Use value may be for uses that are within the market system, making estimate of values reasonably easy. However, they can be outside the market system requiring different techniques to estimate value. Non-use values are outside the market system, and estimates of value have to be extracted from survey questions that reveal willingness to pay.

There are a variety of techniques available for attaching values to outcomes. They range in how broadly they can be applied and in the degree of uncertainty in the estimate. As a guide:

- market prices are widely applicable, but the degree of uncertainty increases with the forecast horizon and the volatility in the market;
- actual costs used as proxies (eg travel cost, hedonic pricing methods, infrastructure repair costs) are highly location specific, but if collected carefully should be reasonably accurate;
- willingness to pay estimates from contingent valuation surveys are highly situation specific, and are not additive;
- choice modelling may have some potential to be more generally applicable. As with contingent valuation, the estimates will change over time as attitudes change; and
- a database of estimates of non-market values is available to provide a first guess at the magnitude of the benefit. Using such information can avoid expensive specific estimations where the situations are sufficiently similar, and the margins sufficiently large, for the required purpose of the overall valuation.

Evaluation of programs does not only require putting values on outcomes - qualitative judgements about meeting objectives are often also necessary and in some cases sufficient. Reducing complex outcomes to dollar values is sometimes inappropriate and the error margins in such estimates are often very large. However, even if the true value cannot be estimated with confidence, the process of thinking about the value of the outcome - in particular to the broader community - is essential for efficient allocation of scarce resources.

The final section of the report presents a brief description of the existing indicator programs.

1 Introduction

1.1 Purpose

This Literature Review was prepared as part of a consultancy on “Measures and methodologies to determine the effectiveness of vegetation management programs, which was funded by:

- Environment Australia (EA), through Bushcare, a program of the Natural Heritage Trust; and
- the Rural Industries Research and Development Corporation (RIRDC), through the Joint Venture Agroforestry Program (an initiative of RIRDC, the Land and Water Resources Research and Development Corporation and the Forest and Wood Products Research and Development Corporation).

The Literature Review was undertaken by a consultant team consisting of the Centre for International Economics (CIE) and the CSIRO, and was presented to EA and RIRDC in October 1998.

The document has been published to allow it to be more widely distributed, for the use of researchers and decision-makers concerned with native vegetation management.

The major purpose of this document is to describe the results of research work on vegetation and its impacts on the biological and physical environment, as well as production and socio-economic outcomes.

In other words, it looks at the evidence as to whether vegetation can be used as a tool to achieve the objectives of programs such as Bushcare and the Farm Forestry Program related to improved soil and water quality, conservation of biodiversity and improved agricultural production.

It also looks at program actions which are directed at changing people and institutions, and whether these can be linked to on-ground conservation and production outcomes.

This summary of relevant research and investigations is designed to assist in:

- determining and analysing the success of current and future vegetation management programs;
- identifying where investment could be targeted to achieve most cost-effective outcomes; and
- identifying those areas where further research is needed to clarify the links between actions funded through vegetation projects, and the outcomes we are seeking to achieve.

1.1.1 The Framework

In order to determine the effectiveness of a vegetation management program, we need to understand the processes linking actions to outcomes. The Evaluation Framework (Chart 1.1) sets out the potential links between vegetation management program activities and final outcomes.

Many final outcomes are expected to arise with a considerable lag so, to develop an appropriate set of indicators, we need to understand the processes by which these outcomes occur. Chart 1.1 outlines the plausible links between actions and outcomes — the processes that need to be understood. These processes attempt to map action — revegetation or protection of existing vegetation — into final outcomes. Most are biophysical processes, but some are sociological or economic in nature. By understanding the processes we can select indicators with greater confidence that they will reflect the extent to which the desired outcomes have been, or will be, satisfied by the actions taken. Where processes are poorly understood, indicators of final outcomes as well as intermediate outcomes and actions are required. These should be selected to inform researchers about the process.

This literature review focuses on these processes. We examine what is known with some degree of confidence, what is yet to be confirmed, and what is not known. The spatial dimension of the process and whether its complexity can be captured in a useful way by a model is also explored.

The Literature Review categorises outcomes into four areas, which accord with the four key outcome areas for the Natural Heritage Trust, the major current Commonwealth initiative funding action in natural resource management. These areas are:

- Environment (Chapter 2)
- Sustainable Production (Chapter 3)
- People (Chapter 4)
- Integration and Institutions (Chapter 4)

Chapter 2 concentrates on the biophysical processes as indicated in chart 1.1, which deliver the conservation outcomes. It examines the links between vegetation management and:

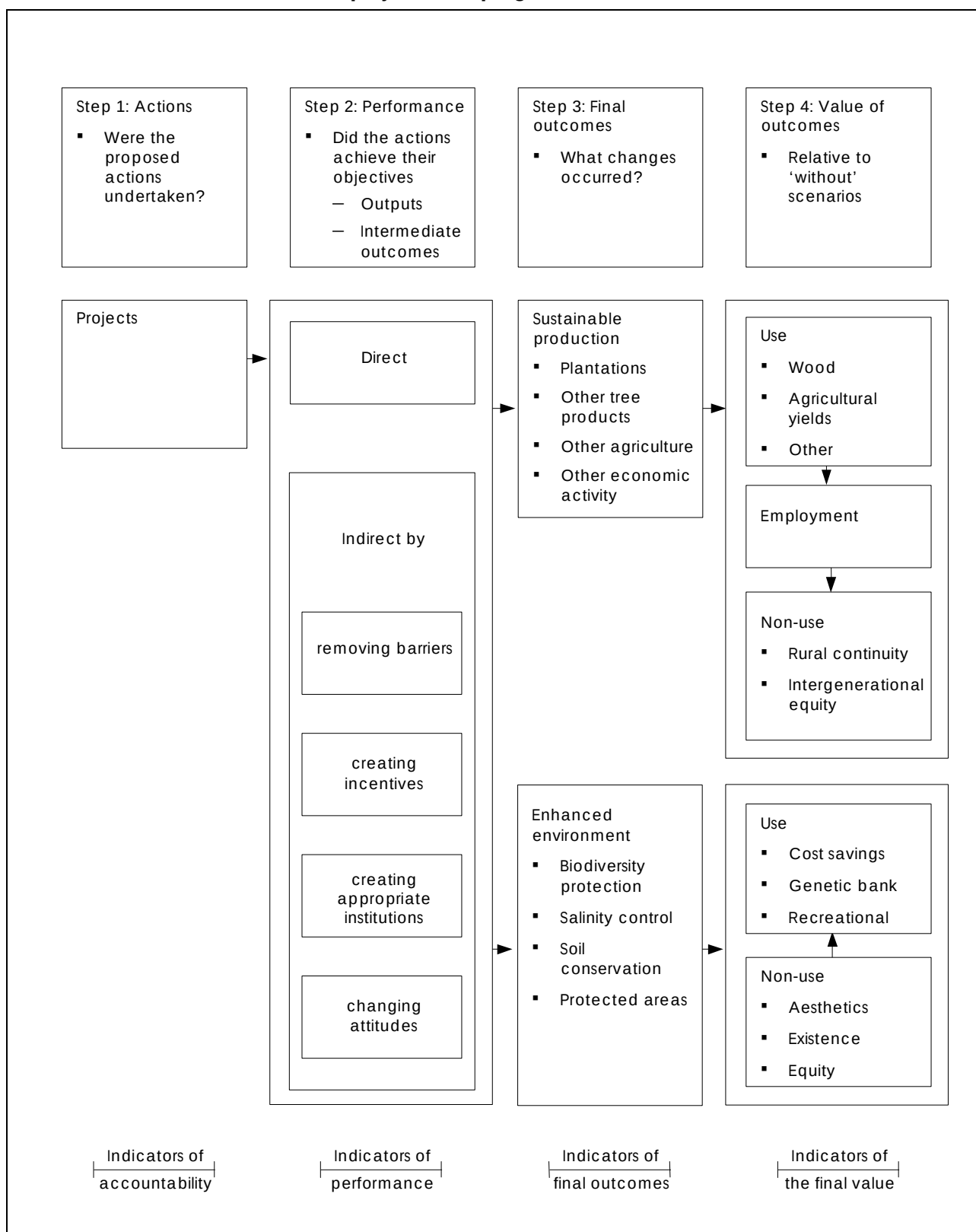
- salinity control — local and regional;
- soil conservation;
- water quality in rivers and streams; and
- biodiversity protection.

It also considers evidence on how these issues are evolving over time. This provides a base against which to assess effectiveness of the programs in achieving environmental outcomes.

Chapter 3 focuses on the processes that deliver sustainable production. Conservation outcomes impact on sustainable production but, in addition, biophysical processes determine the:

- potential for commercial production of wood and non-wood products;
- yields from associated agricultural production processes;
- damage to buildings, roads, bridges and other infrastructure; and
- carbon sequestration.

Chart 1.1 Process for evaluation of projects and programs



Chapter 4 examines the influence of vegetation management programs on actions undertaken by people to improve the physical environment at their own expense. The programs are aimed at improving people's skills, changing attitudes and behaviour, or changing institutions and removing barriers to change. The chapter also summarises methods that can be used to attach values to the final outcomes.

The final chapter provides an overview and summary of the findings.

2 Biophysical processes — conservation outcomes

2.1 Introduction

2.1.1 Key issues

The key issue to be addressed in this chapter is the link via physical processes between project outputs and program objectives as shown in chart 2.1. For example:

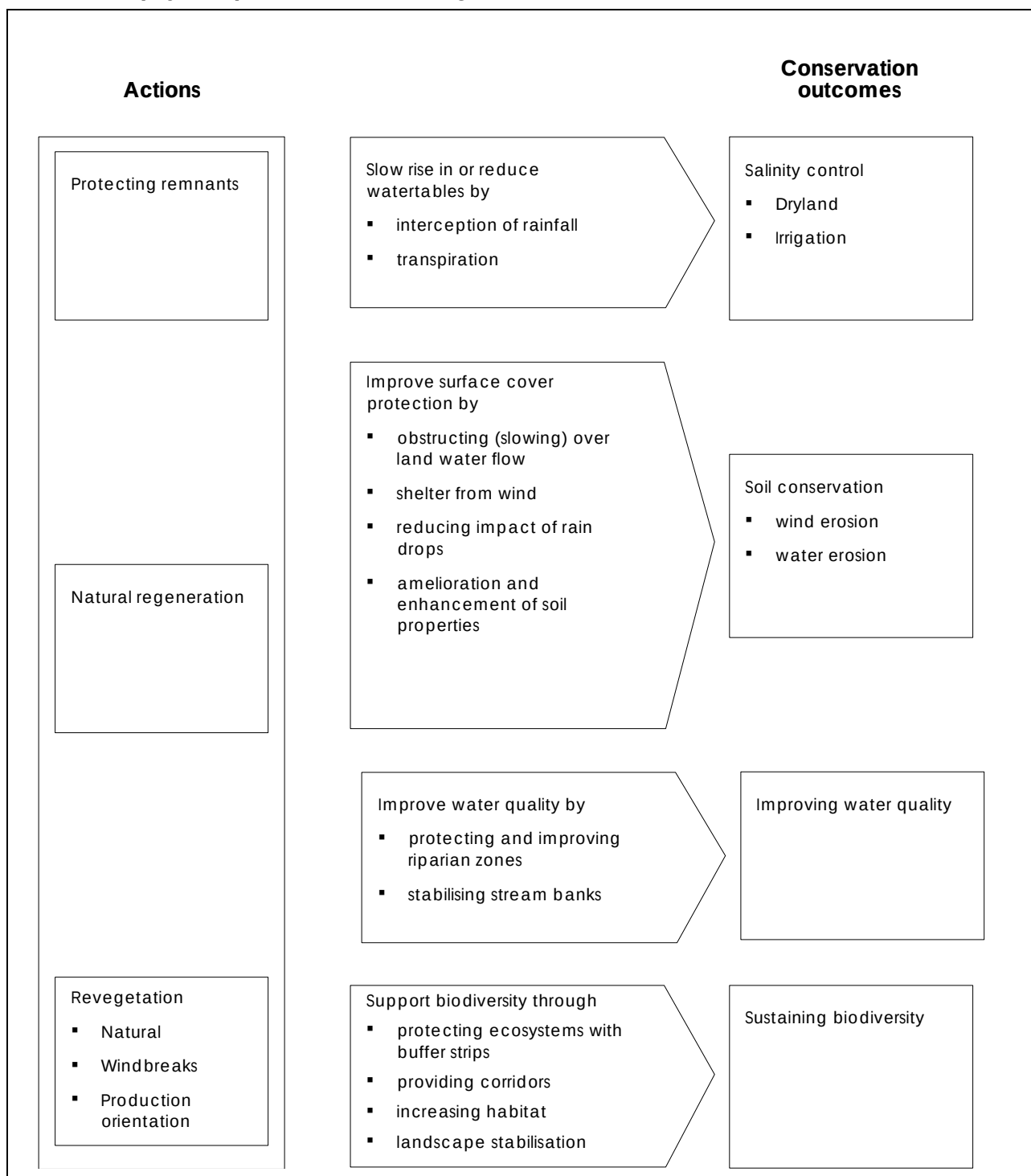
- what is the scientific basis for links between tree and shrubs planting and reductions in soil salinity and increases in agricultural production off-site; or
- what is the scientific basis for tree plantings and increased bio-diversity?

Before describing the methods that were employed in this brief review of the literature, it is important to point out that the intention of this review has been to focus on the management of all forms of vegetation. However, on delving into the literature, it soon became apparent that there was a strong bias in the literature towards material on the biophysical processes associated with trees, and to a much lesser extent, shrubs and grasses. As a consequence, the emphasis in many sections of this report will shift between trees, shrubs and grasses, depending on the relative emphasis in the literature.

2.1.2 Methodology

The Commonwealth Agricultural Bureaux International (CABI) Abstracts and Current Contents databases were searched for relevant literature using the key words Australia, vegetation, tree, degradation, erosion, benefits, biodiversity, agriculture and farm. Key Australian journals — *Rural Research*, *Australian Journal of Forestry*, *Land Degradation and Rehabilitation*, *Australian Journal of Soil and Water Conservation*, *Australian Journal of Environmental Management* and *Trees and Natural Resources* — were also searched systematically for relevant references. Other references were obtained from personal databases, from the reference lists of key papers and on an *ad hoc* basis from other scientists. Australian literature was selected preferentially, but a number of international papers were also included, particularly on topics where the Australian literature was less comprehensive.

Chart 2.1 **Biophysical processes for attaining conservation outcomes**



2.2 Salinity

2.2.1 Overview of the problem

Dryland salinity is regarded as a serious problem in many areas of Australia, particularly in the wheat–sheep areas. Table 2.1 presents some estimates of the areas' commonly affected and the potential for further salinisation.

Table 2.1 Estimates of actual and potential areas affected by salinity

State	Area	Potential	Off-site effects
	'000 ha	'000 ha	
Qld	30	70	Small
NSW	22	Much more	Large infrastructure maintenance cost impacts
VIC	100	400	Large infrastructure maintenance cost impacts
SA	225–300	450	20 per cent of all divertable water is too saline for human consumption
WA	900	2 400	60 per cent of all divertable water is too saline for human consumption

^a Murray-Darling Commission, 1993.

Source: PHD (1992).

Williamson (1986; 1990; 1998) suggests that three essential factors are responsible for the accumulation of soluble salts in a soil profile. These are a source of salt, a source of water and a hydrologic disturbance for redistributing the salt in the landscape.

Source of salt

As recognised by Schofield (1993), the salt responsible for salinisation problems throughout most of Australia is commonly of oceanic origin which, over geological time, has been deposited on land via rainfall and has accumulated in the unsaturated zone of the soil. Other sources include the weathering of soil and rock minerals, and marine deposition in earlier geological periods (Marcar et al. 1995). According to Hook (1992), these processes of salt accumulation are a component of all landscapes.

Source of water

It has been widely accepted that the fundamental cause of dryland salinity is the removal of deep-rooted perennial vegetation and replacement with shallow rooted crops and pastures (for example, Nulsen 1992; McFarlane et al. 1995; Marcar et al. 1995; Williamson 1998). The reduced water consumption resulting from this change in land use leads to increased groundwater recharge and rising groundwater tables. In the case of irrigation salinity,

increased groundwater recharge occurs when the source of water (irrigation and rainfall) exceeds plant requirements and passes below the root zone (Schofield 1993).

Method of redistribution and role of vegetation

Increased salinisation can be linked directly with vegetation clearing and changes in land use which have substantially modified the water balance of local and regional catchments (Walker et al. 1993). According to Walker et al. (1998), the pattern of water use in introduced agricultural systems varies dramatically from that of the original vegetation. For example, cool-season annual crops and pastures are active during the wet winter and early spring period, and senesce (grow old) thereafter. In the case of pastures, the leaf area index is reduced by grazing. Evaporation is also considerably less in the introduced systems than under native vegetation. Tillage and grazing can have a direct impact on the hydraulic properties of soils, while soil erosion has obvious and dramatic impacts on fertility, structure and water-holding capacity. Land degradation issues such as soil acidification, soil structural decline and waterlogging have strong impacts on the hydrological cycle, and impact more on regional scale phenomena such as salinisation and streamflow.

Most current salinity problems have arisen in southern Australia. Nevertheless, Williams et al. (1997) use experimental data and simulation models to estimate the effect of tree clearing and the introduction of perennial pastures in the upper Burdekin catchment in northern Queensland. Their results show increased deep drainage beyond the root zone. This, coupled with high concentrations of salt in the non-saturated soil zone, suggest that a salinity hazard exists in this catchment.

The removal of native vegetation has resulted in a hydrologic imbalance within many Australian catchments and therefore it is not surprising that revegetation of catchments with trees and shrubs is promoted as a remedy to the problem (Hatton et al. 1993; Abel et al. 1997), and retention of existing native vegetation is advocated as a preventative measure (for example, Williams et al. 1997). The use of vegetation to manipulate the hydrologic cycle can take two basic forms — minimising groundwater recharge and maximising groundwater discharge. Of these, minimising groundwater recharge is generally considered to be a much more effective means of remedying the problem because it addresses underlying processes, whereas the other targets the symptoms. Both are discussed in more detail below.

2.2.2 Reducing groundwater recharge

Groundwater recharge is regarded as the movement of water through the unsaturated soil zone to the groundwater table (Schofield 1990). There are two processes by which plants can minimise or prevent groundwater recharge — interception and transpiration. Both processes involve the evaporative loss of water from vegetation (Calder 1992).

Interception of rainfall

The process of interception can be defined as the evaporation of water from the outer surfaces of vegetation during and after a rainfall event (Calder 1992). At times of the year when rain falls predominantly as light showers, the ability of a tree to intercept rainfall may rival transpiration as the primary mechanism by which trees are able to minimise or prevent

groundwater recharge (Morris and Thomson 1983). As such, leaf area and canopy structure should be important considerations when selecting tree species for salinity amelioration.

Transpiration of water from the unsaturated zone

The process of transpiration involves the evaporation of water from the leaves, causing a water potential gradient throughout the entire plant, which ultimately allows the roots to draw water from the soil (Landsberg and McMurtrie 1984). Trees are able to reduce groundwater recharge by transpiring water extracted from the unsaturated soil zone. However, according to Schofield (1990), their effectiveness depends on whether groundwater recharge occurs largely as matrix flow (flow between soil particles) or preferential flow (flow down old root channels and other macroscopic structures). For instance, this author suggests:

Matrix flow is slow and trees, with their deep roots, are effective in transpiring this water, particularly during summer. Preferential flow is fast and trees are less effective in transpiring this water before it recharges the groundwater. (p. 14; citation omitted)

It should be noted that preferential flow predominantly occurs if there is saturation of water at the surface or in the soil below. There are some reports of preferential flow in unsaturated conditions, but this occurs only where the preferred flow pathways extend to the soil surface (Byrne, personal communication).

McFarlane et al. (1995) cite a study that compared water use by an annual crop (lupins) and nearby native heath shrubland in the west Australian wheatbelt. It found that the native vegetation was able to transpire a significant amount of rainfall in summer and autumn, which would have run off, increased soil water storage or become recharge on land supporting the annual crop.

The greater potential for trees to reduce groundwater recharge than crops and pastures ultimately lies in their ability to use more water from deeper in the soil profile over the entire year (Morris and Thompson 1983). The primary features contributing to this effect are a perennial habit and an extensive root system. But Morris and Thompson (1983) also acknowledge that leaf area, canopy structure, and physiological features such as the ability to transpire against high soil water concentration gradients are also important in some species.

2.2.3 Increasing groundwater discharge

According to Abel et al. (1997), groundwater discharge can occur as sub-surface lateral flow, evaporation from soil, and transpiration from vegetation. The direct transpiration of groundwater by trees can occur in two ways: extraction of water from the capillary fringe and extraction of water from within the saturated soil zone (Schofield 1990).

Extraction of water from the capillary fringe

Schofield (1990) defines the capillary fringe as the zone above the groundwater table which consists of groundwater that has been drawn up by capillary forces. The capillary fringe is characterised by greater aeration and decreasing water content as the distance from the watertable increases; therefore, water in the capillary fringe can be readily utilised by vegetation with roots that can access this zone.

Extraction of water from within the saturated zone

Schofield (1990) states that only certain vegetation, termed phreatophytes, are capable of using water contained in the saturated soil zone (groundwater table).

2.2.4 Factors controlling the rate of water use

Transpiration

The many complex factors that control the rate at which a tree can transpire water have been combined by Conservation, Forests and Lands (1989) into three broad groups. These include (1) the availability of water, (2) the energy available to evaporate it, (3) and the capacity of the tree as a conducting pathway.

The availability of water

With regard to reducing groundwater recharge, the depth and density of the roots combined with the water holding capacity of the soil will determine the amount of water that is available for transpiration (Cooke and Willatt 1983). However, in the case of increasing groundwater discharge, groundwater is the obvious source of water. The ability of vegetation planted in discharge locations to use this water is limited by two factors. Firstly, as Schofield (1990) notes, a tree's ability to extract groundwater diminishes with increasing depth, for reasons including:

...decreasing root density, increasing soil bulk density (affecting root penetration), decreasing oxygen level and greater gravitational potential difference (that is, more effort required to lift the water against gravity). (p. 14)

Secondly, Schofield (1990) argues that groundwater extraction by trees decreases with increasing groundwater salinity, due to increased osmotic potential which acts against water absorption by roots.

Input of energy and tree spacing

Stewart (1984) has suggested that the input of energy in the form of solar radiation to vegetation is the single most important factor controlling transpiration. The energy that is available to evaporate water from the leaves of plants will generally determine the upper limit of plant water use (Conservation, Forests and Lands 1989). The actual amount of water used by plants is limited by annual rainfall, unless the plant has access to good-quality groundwater. When water is not limiting, plant water use will depend on the capacity of the tree to act as a conducting pathway and the evaporative potential of the atmosphere.

Climatological stations often measure potential evaporation by using a Class A pan evaporimeter. The amount of evaporation is recorded as the decrease in water level of the pan (positive or negative) plus rainfall. Where water is not limiting, plant water use in some circumstances can exceed pan evaporation (Conservation, Forests and Lands 1989). This occurs in eucalypts that do not exhibit stomatal regulation (Calder 1992), and is due to differences in atmospheric conditions amongst leaves within a tree canopy and those associated with a pan of water (Conservation, Forests and Lands 1989). The rate of

transpiration from such species will be dictated solely by atmospheric demand, where soil water is not limiting.

Water use per tree is usually greater in open grown trees than in trees growing in a forest situation (Stewart 1984, Conservation Forests and Lands 1989). This is a result of better access to soil water and a larger canopy providing an increased evaporative surface (Conservation Forests and Lands 1989).

Another factor influencing water use in isolated trees or trees in small blocks is advection. If such trees have access to water at depths that the pasture or crop cannot reach, the trees will continue to transpire while the pasture or crop plants have closed stomata. The radiant energy incident on the pasture/crop will be dissipated as heat, raising air temperatures and vapour pressure deficit. This air advected onto the trees will raise their transpiration rates per unit leaf area above those that may be expected for the same trees in a larger stand (Landsberg, draft manuscript).

Seasonality

With regard to seasonality, Clifton et al. (1993) suggest that the actual daily water use of eucalypts can vary from virtually nothing in winter, to 130 litres day⁻¹ in summer, providing moisture is not limiting. And there is considerable variation across species.

2.2.5 Evaluating the effectiveness of vegetation

Nulsen (1993) advises caution when interpreting water use studies, as the results vary depending on species, age, climate, soils and position in the landscape. Furthermore, it is important to note that virtually all of the experimental observations concerning direct measurement of the effect of vegetation on salinity are confined to vegetation planted in the discharge zone.

Direct measurement

Thorburn (1996) reviewed the results of eighteen studies on the groundwater uptake rates from plants in saline areas of Australia, and compared these with discharge rates from bare soils. Eleven of these were dryland studies focusing on the water use of native trees and shrubs, while the remaining seven were irrigation studies based on the water use of agricultural crops and pastures. The experimental methods used in these studies fall into three broad categories: (1) the partitioning of measured transpiration rates into soil water extraction and groundwater uptake; (2) the direct measurements of water withdrawal from watertables in lysimeters; and (3) the measurement of chloride accumulation in the root zone. The major findings of Thorburn's study are now briefly discussed.

The rationale for many of the studies reviewed by Thorburn was that:

One measure of the potential impact of plants on watertable levels is to compare the groundwater uptake rates from plants with discharge rates from bare soils, assuming that the bare soil condition is the 'do nothing' management option. (Thorburn (1996); p. 48)

However, according to Thorburn there was very little experimental data to provide such a comparison. Therefore in the absence of experimental data, he argues that soils physics theory provides a means by which to estimate groundwater discharge from bare soil. Based

on the assumption that depth to watertable and soil hydraulic properties are the factors primarily responsible for controlling groundwater discharge from bare soil, Thorburn (1996) was able to show that:

... discharge increases greatly as watertables become shallower, and is higher in coarser textured soils because of their greater ability to conduct water. (p. 48)

Hence, when comparing groundwater uptake by plants as opposed to discharge from bare soil, Thorburn (1996) concluded that:

... uptake of groundwater by plants has the potential to be much higher than discharge from bare soils, provided that (1) watertables are deep (for example, > 3 m), (2) the plants roots are close to the watertable and (3) the plants salinity threshold is at least two times greater than the watertable salinity ... If either roots cannot penetrate close to the watertable or groundwater salinity is high, uptake rates are similar to discharge rates from bare soils. Where watertable depths are shallow (for example, 1 m), plants have a restricted capacity to take up more groundwater than would discharge from a bare soil ... Comparison of the uptake and discharge rates in two soil types (clay and loam) shows that potential increase in uptake rates relative to bare soil discharge is greater in finer-textured soils. (p. 49)

Thorburn (1996) acknowledges the concerns raised by Morris and Thompson (1983) and Williamson (1986) over the long term sustainability of discharge plantings because of the potential for buildup of salts in the root zone. But he suggests that in areas where rainfall is high enough:

rain during the wet season may be able to leach the soil sufficiently to maintain enough depth of salt-free soil to survive. (p. 49)

But, he also cautions that:

... if rainfall amounts are highly variable and watertables are shallow the survival of vegetation may be uncertain. (p. 49)

In summary, it is apparent from the comprehensive review conducted by Thorburn (1996) that, in the case of shallow watertables at least, there is little evidence to support the long held belief that vegetation will take up significantly more water than would be lost from the soil if it was bare (that is, a 'do nothing' management strategy).

However, the lack of experimental evidence to support the estimates of water loss from bare soil is a major weakness of the work. If his theoretical calculations are confirmed by experimentation, vegetation may only have a beneficial impact on lowering watertables where these are relatively deep and of low salinity, and where the soils are of a fine texture (for example, clay).

Indirect measurement

Other methods of inferring water uptake rates, such as the measurement of watertable level fluctuations or transpiration, are considered to be less direct than those described above, and hence the results may be confounded by greater uncertainty (Thorburn 1996). Nevertheless, such studies conducted primarily in Western Australia and Victoria have provided some useful insights, and these are now discussed.

In the southwest of Western Australia, Schofield et al. (1991) tested four partial revegetation strategies for controlling dryland salinity. These include: lower slope and discharge zone planting; wide spaced plantations; strips or small blocks strategically placed but covering less

than 15 per cent of the cleared area; and dense plantations covering at least 50 per cent of the cleared area.

The results can be summarised as follows. Firstly, lower slope and discharge plantings tend to cause a localised reduction in watertables beneath the revegetation, whilst wide spaced plantations will significantly reduce watertables under pasture as well. Strips or block plantings covering less than 15 per cent of the cleared area had little or no effect on the watertable. Dense plantations covering at least 50 per cent of the cleared area drastically reduced the watertable underneath the plantations, but had little or no effect on the watertable beneath the pasture.

Clifton et al. (1993) report that two main tree growing strategies are recommended in the salinity management plans of the hill country in Northern Victoria. The first strategy includes the establishment of high density plantations (200–500 trees per hectare) on small strategic areas of high recharge, while the second strategy includes low density woodlands (20 trees per hectare) on extensive areas of high recharge or those areas not suited to perennial pastures.

Investigations into the value of these revegetation strategies for dryland salinity amelioration by Clifton et al. (1993) have produced some tentative conclusions. Low density woodlands will evaporate more water than open pastures, and will also dry the soil to a greater extent and depth than open pasture. However, the low planting density means that it will take several decades before recharge is prevented. Moreover, in areas of medium to high rainfall, low density woodlands may not be able to completely prevent recharge at maturity. High density plantations (200 trees per hectare) were not effective at using water within the entire tree planting space. It is argued that since competition between trees is unlikely during the establishment phase, a doubling of this planting density should nearly double evaporation. Consequently the length of time until recharge is totally prevented would be halved. Clifton et al. (1993) now recommend 500 trees per hectare in the high density plantings.

In addition to the planting strategies above, there is increasing promotion of the ‘break of slope’ planting strategy in North East Victoria (Treecorp Pty Ltd 1993). The ‘break of slope’ is defined as the area between steep hills with slopes of up to 1:10 and the valley floors with slopes of around 1:250. This area generally has soils ranging in depth from 1–30 metres and groundwater available for the tree roots. It is this area that is usually preferred for farm forestry.

Predictive modelling

Hatton et al. (1993) have advised that the ability to forecast the expected effectiveness of revegetation for salinity control remains largely intuitive and subjective. Furthermore, they suggest that as with many plant ecological problems:

reliance on experimental determinations of treatment effectiveness means that answers to today’s problems may be unavailable for decades, and even then questions inevitably remain regarding the extent to which experimental inference may be extended in space and time. (p. 274)

As such, Hatton et al. (1993) argue that:

There is clearly a need for a modelling framework, first to estimate how effective specific changes in vegetation will be in altering local and regional water balances, secondly to identify landscape problems which demand an engineering solution. (p. 274)

Hatton et al. (1998) review a number of models of catchment water quality and their ability to predict the consequences of land use changes. They list the attributes of an 'ideal' model and suggest that no current model achieves a reasonable balance between 'ideal' attributes. Williams (1998) provides an overview of the capacity of current models to predict production and the effect of dryland farming systems on catchment land and water quality and identifies a number of gaps. For example:

all (catchment hydrology models) suffer from a general weakness of not being able to link the movement of sediment, nutrient and pollutant through the catchment, with farming systems. (p. 270)

Thorburn (1996) concludes that many factors influence groundwater uptake, hence making it extremely difficult to generalise about uptake rates from experimental observations. As such, he asserts that modelling of the interaction between plants and watertables is required to assess adequately the impact of plants on groundwater discharge. Further support for modelling is provided by Williams (1998) and by Dawes and Hatton (1991) who suggest that there is probably no other way to describe and predict the complex interactions between land, vegetation and climate.

Clarke et al. (1998) note that there are many different computer programs in use in Australia to model salinity risk and the effect of revegetation strategies (see Hook 1997). But in a recent study located 185 km south-southeast of Perth, Western Australia, Clarke et al (1998). chose to use the Western Australian Water and Rivers Commission's (WRC) groundwater, hydrology modelling program MAGIC. Several different revegetation strategies were modelled and compared with the base case, which represented the vegetation in a 1991 landsat image. The results show that:

... the best compromise to minimise degradation and the disruption of the current agronomic system would be to incorporate a deep-rooted perennial pasture plant in mid-slope bays of an alley-farming system, where the remnants of native vegetation have been fenced and rehabilitated.

... neither block planting nor alley planting of trees on their own will rid the catchments of salinised or saline seepage and increased streamflow. The rehabilitation of remnants of the native vegetation to their pristine condition gives a significant improvement in all of these parameters and should be implemented in areas where there is a significant proportion of such vegetation, although as for block and alley planting's, it failed on its own to prevent completely land and stream salinisation. If all of the annual pasture is replaced by a deep-rooted perennial pasture or pristine native vegetation, seepage area and seepage volume are reduced to minimal values, whereas streamflow is less affected ... (p. 125)

Farrington and Salama (1996) suggest that a number of important questions are raised when tree planting is being considered as a long term strategy for controlling salinity. For instance, if trees have to be planted in limited areas of catchments:

... what is the best strategy for controlling the excess recharge generated by clearing? Where is the best place in the catchment to plant trees? What is the minimum area of plantations required to control salinity? How can tree planting be best combined with the other vegetation and engineering measures? [p. 184]

Greenwood (1992) suggests that for any one region, quantitative or semi-quantitative data should be obtained on:

- annual discharge (mm yr⁻¹) of a range of species from ground cover to trees.
 - Change in water use with age
 - size location and number of plantations
- The more explicit the information from a wide range of sites, the more effective (hydrologically and economically) will be the reclamation. (p. 3)

2.3 Soil conservation

2.3.1 Overview of the problem

Estimates suggest that a significant proportion of agricultural land in Australia is affected by soil degradation through wind and water erosion and a decline in soil structure and its properties such as acidity and water repellence. Tables 2.2 and 2.3 provide some estimates of the extent of the problems.

Soil erosion is a land degradation problem of major concern due to its often detrimental effect on plant production (Rose 1992). It can take many forms (Abel et al. 1997), but there are primarily two causative agents: wind and water. Most research in the past has concentrated on the processes of water erosion, although as pointed out by Rose (1992) research into wind erosion processes is increasing rapidly.

Table 2.2 Estimates of land degradation by state and land use 1991

	NSW	QLD	VIC	TAS	SA	WA	NT	Australia
	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha	million ha
Soil structure decline/compaction								
Extensive cropping	3†293.1	1791.4	1418.7	12.3	1680.4	4180.8	0.0	12.4
Intensive cropping	468.6	110.1	274.9	13.0	69.1	2.9	0.0	0.9
Grazing	3†816.1	0.0	2613.1	0.0	1802.8	4101.6	0.0	12.3
Water repellence								
Extensive cropping	1.5	0.0	0.0	0.0	50.0	619.9	0.0	0.7
Grazing	4.5	0.0	0.0	0.0	100.0	300.0	0.0	0.4
Water erosion								
Extensive cropping	4†493.5	2396.3	1916.1	31.5	2707.4	5356.0	7.6	16.9
Intensive cropping	9.7	113.4	5.9	7.5	7.8	4.3	0.0	17.1
Grazing	1†445.6	4343.3	1635.9	119.1	3789.7	6280.5	969.0	18.6
Wind erosion								
Extensive cropping	58.0	2.0	5.7	0.0	60.7	1589.1	0.0	1.7
Grazing	133.2	215.5	1.3	0.0	482.6	149.5	157.4	1.1
Area of state	8†0160.0	172†720.0	227†60.0	6†780.0	9†8400.0	252†550.0	134†620.0	768.0.

Source: DPIE (1991) unpublished; Lindsay Northrop, (DPIE, Canberra, personal communication) (in CIE (1997)).

Table 2.3 Miscellaneous post-1990 estimates of total areas impacted by land degradation

Soil health issues by state

	NSW	QLD	VIC	TAS	SA ^a	WA
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	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha
Soil structure decline/compaction	14 695	2 645	10530	317		1 300
Waterlogging						1 800
Water repellence						5 000
Water erosion					2 900	750
Sheet and rill	2 288	1 343	3 180	226		
Gully and tunnel	9 460		4 220	340		
Wind erosion	20 045	74 000	1 630	321	8 300	50
Wind/water in rangeland						7 300
Sodicity						
Acidity			7 610			
Mass movement				270		
Area of state	80 160	172 720	22 760	6 780	98 400	252 550

Note: Blank cells indicate no data found as yet. Figures are not exclusive — a given area may have several types of land degradation.

^a South Australia figures refer to potential areas that may be affected. Soil and Water Conservation Branch, SADA total annual losses \$120 million (includes salinisation \$27 million, rabbits \$17 million).

Source: Soil Conservation Service (1989); Office of the Commissioner of the Environment (1991); Grice (1995) (in CIE (1997)).

It is useful to note that wind and water are both fluids, and hence there are some fundamental similarities, as well as differences, between the erosive processes of wind and water erosion. For instance Rose (1992) suggests that while there is no direct analogy to rainfall detachment (that is, the dislodgment of soil material by raindrops) in wind erosion:

there is direct equivalence in the process of sediment deposition, and broad similarities in the processes of erosion which result from the mutual shear stresses between the fluid and the surface over which it flows. (p. 6)

However, one fundamental difference is that in wind erosion:

... water in the soil is the major stabilising agent through capillary forces which effectively strengthen the soil against the erosive effects of winds. (p. 6)

But can trees and shrubs control the processes of wind and water erosion? Abel et al. (1997) express the widely held view that they can, although a study on the influence of pasture management on runoff and soil movement near Charters Towers in Queensland, found that higher runoff and soil movement values were recorded in native woodland plots than in untreed (but pastured) plots (McIvor et al. 1995).

With regard to water erosion, there are essentially two different types of protection that can be provided. For instance Rose (1992) states that trees and shrubs can help to control water erosion by firstly providing surface cover on the ground, such as leaf litter, and secondly through the provision of aerial cover, such as living branches and leaves.

McIvor et al. (1995) found that runoff and soil movement were related to groundcover levels: the cover level required to reduce these factors increased with the size of rainfall events. They suggest that cover reduces the amount of rainfall detachment, increases the flow depth and reduces flow velocity.

Since there is no direct equivalence to rainfall detachment in wind erosion, cover of any kind is effective in retarding wind erosion (nevertheless, trees have much more effect on reducing wind erosion off-site than do forms of groundcover that are low to the ground). In addition to the provision of cover, Abel et al. (1997) suggest that trees and shrubs can help reduce soil erosion by holding the soil together and increasing infiltration.

In summary, there appear to be three main processes by which vegetation can help control soil erosion: (1) the provision of surface cover protection from wind and water, (2) the provision of aerial cover from water (although such cover may actually increase the energy per mm rainfall available for erosion by increasing drop size: McIvor et al. 1995), and (3) the amelioration and enhancement of soil properties. These three processes are now discussed in more detail.

2.3.2 Surface cover protection from wind and water

Obstruction of overland water flow

The most obvious form of water erosion is gully erosion. Abel et al. (1997) advise that the best means of controlling gully erosion is to reduce the flow of water to the gully rather than the actual erosion within the gully. In other words, effort should be placed into remedying the underlying cause of the problem instead of the symptom. Abel et al. (1997) acknowledge that the slowing of overland water flow may not prevent gully erosion completely, but suggest that it can dramatically reduce the rate at which it proceeds. According to these authors:

Leaving tree stumps and stones in place will slow water flow. The occurrence of tree trunks, grass tussocks, logs or other obstructions and the lying of branches on the contour are also ways of decreasing water flow. (p. 33)

Further to this, Tongway and Ludwig (1997) suggest that:

the spatial re-distribution of materials such as litter and soil particles, by wind and water across a landscape is regulated by two factors: terrain and vegetation. (p. 14)

These authors suggest that landscapes with very rough terrain (that is, complex shapes and slopes) will influence the transport of materials to a much greater extent than smooth, long, open terrain. Abel et al. (1997) provides support for this view, stating that the rougher the ground the slower water will flow. McIvor et al. (1995) are less dogmatic, since their results indicate that:

current understanding of surface hydrology on hillslopes with low slope and with rough surfaces is incomplete.

Nevertheless, their results suggest that the velocity and depth of overland flow is not consistently increasing with increasing length of slope and that the variation along the slope is at least as great as any systematic increase with distance down the slope. If these and other suggestions are confirmed:

then maintenance of surface roughness will be an important aspect of plant cover management. (p. 62)

Vegetation also exerts a strong influence on the transport of materials. For instance, Tongway and Ludwig (1997) provide the example of perennial grasses which cause water flow to become more tortuous, resulting in the slowing of water flow, and increasing the time available for infiltration. Furthermore, they state that the obstruction to overland flow afforded by perennial vegetation clumps can trap or filter litter and sediment out of flowing water, causing sedimentation.

As alluded to earlier, the length and steepness of a slope have an impact on the rate of water flow. Abel et al. (1997) argue that the distance between rows of trees that are planted on the contour impacts upon slope length and consequently, the rate of soil loss.

Fitzpatrick (1994) claims that the key to solving water erosion problems is to restore the ground cover, therefore the focus on vegetation as a control strategy must revolve around the use of grasses, shrubs and litter producing trees. This assertion is made on the basis of observations by Fitzpatrick of native forest communities which have experienced severe sheet and rill erosion, despite the trees, resulting from excessive grazing or fire which has reduced the ground cover. Similar accounts are provided by Heinjous (1992), who states that trees with a sparse canopy and a shallow rooting system, which may restrict the growth of ground cover vegetation species, are probably not the most appropriate for the control of water erosion. Similarly, McIvor et al. (1995) found that by reducing tree canopies (by killing the trees), grass growth increased and rates of runoff and soil movement decreased. Hairsine and Prosser (1997) report that cover levels of 70 per cent or greater are recommended to reduce upslope erosion in pastures.

Shelter from wind flow

The rate of soil erosion by wind is affected by soil type, ground cover, shelter and windspeed (Abel et al. 1997). McTainsh et al. (1990) demonstrate a relationship between wind erosion, mean annual windspeed and soil moisture.

Each soil has a particular propensity to erode, but Bird et al. (1992) consider that soils of a sandy nature are particularly prone to wind erosion.

As noted by Rose (1992):

In general, agronomic measures (and especially cover) which are effective in reducing water erosion are also likely to be effective against wind erosion. (p. 7)

There are two primary factors which need consideration when designing a windbreak to maximise shelter (Abel et al. 1997). The first is windbreak structure, which includes factors such as porosity, shape, width, length and height, while the second is windbreak layout, such as orientation, spacing and configuration.

Windbreak structure

Abel et al. (1997) asserts that claims of porous windbreaks providing shelter over larger areas than dense windbreaks are exaggerated. As such, these authors state that windbreak porosity is probably of less importance than windbreak height, which determines the shelter

distance. They consider that an ideal windbreak will have a uniform porosity along both its length and height, and will be as long as possible (at least 20 times the windbreak height).

Windbreak layout

Abel et al. (1997) suggest that the best windbreak orientation is at right angles to the prevailing wind. Sizeable shelter benefits are achieved with spacings between windbreaks of 20 times the height of the windbreak (Abel et al. 1997), although this number appears to be open to conjecture as Harrison (1993) reports that the soil will only be protected at a distance up to 10 times the windbreak height. Recent research by Cleugh (1998) sheds some light on this debate. In her study on the effect of a six metre tall pine windbreak on microclimatic variables on a grazed paddock near Canberra, Cleugh (1998) found that:

... the maximum shelter (at a height of two metres) is found at a distance of five windbreak heights downwind from the windbreak, but a shelter effect continues to extend to 20 windbreak heights downwind. Shelter increases both temperature and humidity, with the largest increase occurring at about five windbreak heights – similar to the location of minimum wind speed. But this increase in temperature and humidity is relatively short-lived, extending to only about 12 windbreak heights downwind in the field data. After that point the air is slightly cooler then returns to the upwind temperature and humidity. The field data suggests this cooling effect occurs after about 12 windbreak heights where enhanced turbulence generated by the windbreak starts to affect the air near the ground. Wind tunnel data also show that surface temperatures start to cool at about 10 windbreak heights. p. 38-39

Therefore it would appear, that the truth lies somewhere in the middle. That is, the effect of a windbreak on wind speed would appear to extend a greater distance into the paddock than the effects on air temperature.

According to Marshall (1990) trees that are planted in windbreaks as well as retained stands of natural vegetation, have an important role to play in protecting the soil against wind erosion, when combined with appropriate management of stock, pasture and crop.

Bird et al. (1992) provide anecdotal evidence to support this view, through observations of the performance of windbreaks during the severe dust storms experienced in Victoria during the summer and autumn of 1983. They suggest that:

Where windbreaks were present the damage was reduced, but much sand was deposited to the windward and through the belt. There were insufficient belts to prevent the windspeed from recovering in the intervening space. (p. 65)

But Marshall (1990) cautions that:

... while well planned and efficient windbreaks can provide useful shelter for a distance equal to approximately 15 or 20 times their height, the breaks would need to be spaced less than half a kilometre to give overall protection against erosion by wind. It can be seen that such a high density of windbreaks would be impractical on most rural properties and that protection from wind erosion would best be achieved with sound pasture and cultivation management as well avoiding the clearing or disturbance of soils prone to wind erosion. (p. 373)

2.3.3 Aerial cover protection from water

Harrison (1993) suggests that the energy of a raindrop is sufficient to dislodge small particles from stable soil aggregates. The role of trees in mitigating this process of erosion is alluded to by Marshall (1990):

Trees can intercept rainfall, absorbing much of its energy by breaking up the raindrops and reducing their velocity. (p. 369)

However, Marshall warns that:

Water dripping from a high tree can accumulate into large drops, quickly regaining velocity and can destructively impact on the soil surface with raindrop splash and soil-structure breakdown. (p. 369)

This phenomenon has been observed by Rose (1992) in grain crops, which he states are effective at intercepting raindrops (aerial cover), but have very little surface contact cover to protect against subsequent erosive forces. Rose (1992) refers to such crops as ‘erosion-inducing’. He suggests that fortunately:

... trees and shrubs, through leaf-fall in particular, provide surface contact cover on the ground in addition to the aerial cover provided by their living leaves and branches. (p. 5)

Following on from this, Marshall (1990) makes the important point that shrubs, ground cover plants and/or litter are all vitally important for the protection of soil surfaces under trees.

2.3.4 Amelioration and enhancement of soil properties

The role that trees and shrubs can play in the amelioration and enhancement of soil properties has been concisely summarised by Ryan (1990):

... tree roots can be a source of organic matter through root ‘sloughing’ and decay. Root exudates are a major energy source for micro-organisms including mycorrhizae fungi and free-living, N-fixing bacteria. Mycorrhizal fungal hyphae can also exude organic compounds such as oxalic acid which attack soil minerals releasing unavailable nutrients. Old root channels are important routes (macropores) for rapid infiltration of rainfall to subsoil. Roots and mycorrhizae enmesh soil aggregates increasing soil strength and resistance to erosion. Penetration and growth of roots will compress and shear soil, increasing bulk density in their vicinity, and in some cases creating cracks and voids. Water uptake by tree roots can rapidly diminish soil moisture content to considerable depth causing soils to undergo numerous wetting –drying cycles which can promote aggregate stability, disrupt compacted layers, and improve soil structure. (pp. 51-52)

Noble and Randall (1998) have also reviewed the effects of trees on soils, canvassing effects on soil chemistry, nutrient cycling, soil physical properties and the rehabilitation of saline/alkaline soils. They found that trees can have both positive and negative effects: for example, trees can help maintain soil organic matter, but they may also contribute to fertility declines.

Abel et al. (1997) suggest that trees can improve soil properties in three main ways. Firstly they can bind the soil with their deep and permanent roots, which in turn can draw moisture from deep within the soil, hence improving soil structure (see also Marshall 1990). Secondly, they can facilitate the recycling of nutrients through the production of organic matter. The final mechanism by which trees can affect soil properties is through the decay of roots and subsequent creation of macropores which enhance soil infiltration.

Noble and Randall (1998) add that in some arid and semi-arid pastoral ecosystems, trees can also improve soils by reducing soil temperatures and water loss due to evapotranspiration and by attracting birds and large mammals that add nutrients to the soils in their droppings.

Acidification

According to Noble and Randall (1998), soil acidification affects about 17 million hectares of agricultural and pastoral lands in Australia, caused mainly by nitrate leaching (which leads to a depletion of exchangeable bases on the exchange complex), product removal and the excessive application of nitrogenous fertilisers. Noble and Randall (1998) suggest that trees can play a role in reversing soil acidification through the development of deep root systems that are capable of taking up bases such as calcium and magnesium from deep in the profile and returning them to the soil surface as leaf litter (thus, surface amelioration would be achieved at the expense of soil acidification deep in the profile). However, Noble and Randall (1998) note that direct evidence of trees increasing soil pH is scant.

Structural Improvements

McKenzie (1990) has noted:

The wetting, and drying by deep rooted plants, of cracking clays causes structure regeneration due to swelling and shrinking. Old crack lines transmit oxygen to the subsoil under wet conditions and allow roots to bypass hard layers. (p. 34)

However, he also suggests that hardsetting loams cannot be regenerated in this manner because:

... suitable clays are not present. Therefore, improvement of aggregate stability is recommended; usually it is best achieved by encouraging organic matter accumulation (p. 35)

This is recognised by Moran (1998) who claims that the major cause of loss of aggregate stability in Australian soils is a reduction in organic bonding agents. However, he highlights the fact that little work has been undertaken to identify what is necessary for rebuilding organic bonds. Moran (1998) believes that the answer lies in being able to identify:

... the components of soil organic matter critical to soil structure and developing techniques for its input and maintenance. Such techniques will probably involve encouraging biological activity to convert raw organic material into suitable long term cements. (p. 155)

Despite detailed knowledge of the mechanisms Abel et al. (1997) suggests that organic matter does improve structure, but that the rate at which litter decomposes to organic matter is affected by the ratio of carbon to nitrogen in the soil. According to Abel et al. (1997) the greatest contribution of litter to organic matter is provided by those leaves that are high in nitrogen.

Production of organic matter and nutrient recycling

Abel et al. (1997) point out that:

Trees recycle nutrients by taking them up from depth and depositing them on the soil surface as litter, which then decomposes to form soil organic matter. (p. 36)

According to Abel et al. (1997) leguminous trees can usually add more nitrogen to the soil than other types of trees, but some species (such as certain acacias) seem to produce litter which decomposes very slowly. Therefore they assert that tree species and local conditions will ultimately determine the actual amount of nitrogen that is added. Further to this, they suggest that because organic matter is predominantly accumulated under trees, the challenge is to design tree planting so that nutrients being recycled are made available to crops and animals.

Infiltration enhancement

Abel et al. (1997) assert that:

... the more soil organic matter the greater the activity of soil organisms and the more channels they make for water entry to storage. All vegetation forms root channels which promote the entry of water. (p. 33)

The creation of macropores by roots that are able to penetrate compact layers of soil can be particularly effective means of increasing hydraulic conductivity in areas of high soil compaction.

Abel et al. (1997) indicate the valuable role that trees can play in soil conservation, but Heinjus (1992) notes:

The inherent characteristics of some tree species make them more effective than others in combating soil loss. The canopy type and density, branching pattern, root structure and growth pattern of a tree all influence its effectiveness as an erosion control agent. Some tree types and trees growing in the wrong position can seriously aggravate an erosion problem. (p. 49; citations omitted)

Heinjus (1992) goes on to state that there are certain situations in which tree planting is *not* a suitable solution to erosion control:

- broadacre erosion in agricultural areas where the land is used for cropping or grazing;
- gully stabilisation where the gully sides are steep;
- drifting dunes or stabilised sandy soils which have a reasonable expectancy of remaining stable once a cover crop has been established;
- grassed waterways; or
- waterways in which erosion has been controlled with concrete structures or rock gabions. (p. 49)

2.3.5 Predictive modelling

- The universal soil loss equation has been widely used to estimate the impact of wind events on soil.
- Marcar (1998) advises that a model titled SCUAF (Soil Changes under Agroforestry) which was developed by Young et al. (1987) is the only model capable of predicting the effects of specified agroforestry systems on soils in different climates. He suggests that since there are so many interactions in the tree-soil system, process-based models will not be available to cover all of these processes in the near future.

2.4 Water quality

2.4.1 Overview of the problem

There is considerable ongoing activity in measuring the quality of water in the river systems, both as part of the NLWRA and in a LWRRDC initiative that is being continued by DPIE called AUSRIVAS. This is a national water quality monitoring and evaluation system that is currently being established. However to date the evidence on the extent of the problem is largely regional. Table 2.4 reports the results from a 10 year monitoring program in Victoria on turbidity trends, turbidity reflecting the amount of suspended material in the river. Table 2.5 provides the results on changes in salt load increase in rivers following clearing for agriculture. Clearly turbidity, but particularly salinity, are issues in river health.

Table 2.4 Turbidity trends and conditions on freehold land, Victoria 1981–91

Condition	Turbidity trend	Sites	
		no.	%
Excellent	Increasing	51	18.1
	Stable	140	49.8
	Decreasing	21	7.5
		212	75.4
Good	Increasing	8	2.8
	Stable	13	4.6
	Decreasing	1	0.4
		22	7.8
Moderate	Increasing	1	0.4
	Stable	5	1.8
	Decreasing	1	0.4
		7	2.5
Poor	Increasing	4	1.4
	Stable	9	3.2
	Decreasing	2	0.7
		15	5.3
Degraded	Increasing	3	1.1
	Stable	21	7.5
	Decreasing	1	0.4
		25	8.9
Total		281	100.0

Source: ABS (1996).

Table 2.5 Examples of salt load increases in rivers following clearing for agriculture

<i>River catchment</i>	<i>Factor by which salt load has increases</i>
Dale River (Western Australia)	19
Collie River (Western Australia)	15
Axe Creek (Victoria)	10
Avoca River (Victoria)	10
Finniss River (South Australia)	8
Brenner River (South Australia)	6
Hughes Creek (Victoria)	4
North Para River (South Australia)	4

Source: ABS (1996).

It was not until the late 1980s that people began to appreciate the critical role that riparian zones play in the linkage between streams and their catchments Lake and Marchant (1990).

For instance, these authors state that riparian zones may:

... shade streams, lowering primary production and decreasing temperature fluctuations. It may also stabilise the stream channel and its banks, contribute organic matter vital to the functioning of the detritivore communities, moderate sediment, nutrient and water inputs and contribute large woody debris to the stream. (p. 80)

These factors are discussed in the next section in relation to: (1) the role riparian vegetation can play in ameliorating ecological function of streams, and (2) the role of vegetation in physically stabilising stream banks.

2.4.2 Riparian buffers to ameliorate stream function

Carter (1992) highlights a number of pertinent information gaps and issues regarding the use of riparian vegetation to maintain/enhance water quality.

- The condition (structure and composition) of the vegetation within a strip and its relationship to functions needs more detailed analysis.
- The impact and fate of nutrients and other pollutants in the riparian zone is not well known. Therefore the actual sustainability of their use for this purpose is debateable.
- Should riparian zones be of a fixed width or should their width vary depending on patterns of overland flow, overbank flow and minor drainage lines?

The reduction in vegetation cover within many catchments has resulted in a reduced ability of catchments to retain nutrients and leads to nutrient leakage into streams (Lake and Marchant 1990). Washusen and Reid (1996) have implied that the potential of trees and shrubs to improve water quality will depend largely on the source of nutrients and their pathways. They state that it is fundamental to distinguish between point and diffuse sources of nutrients.

With regard to point sources of nutrients (such as septic tanks, dairies and refuse areas), Washusen and Reid (1996) warn that trees, particularly eucalypts, may have some serious limitations in their effectiveness as a control. For instance, they state the following.

- Waste water can only be pumped onto trees when soil moisture levels are low. In high rainfall areas this may be limited to late summer.
- Once a plantation of eucalypts closes its canopy all its nutrients requirements are met by recycling. Any additional nutrients added to the site will be either bound to the soil or leached off site.
- Nutrients within the plants must be harvested and removed offsite. Wood is relatively low in nutrients, the bulk being held in the bark, leaves and small branches. Commercial markets for these are limited.
- Continual addition of effluent high in salts may result in a decline in soil structure resulting in reduced soil permeability and therefore plant growth.
- Most agricultural point sources, such as dairy sheds, are on high value land. Removing flat or gently sloping land with soils of good structure, as required for an effluent plantation, is unlikely to be acceptable to farmers. (p. 62)

Washusen and Reid (1996) are slightly more optimistic about the prospect of buffer strips of grass and trees as a means of intercepting some of the nutrients from pastures and crop lands (diffuse source). They advise that nutrients are transported in solution or on soil particles by overland flow, and that sediments are best trapped by dense ground covers such as grass. With regard to the use of trees and shrubs they caution that species selection should be biased towards those which maintain or enhance ground cover vegetation. Furthermore, they argue that the dense planting of eucalypts will promote bare ground and therefore should be avoided.

In contrast, Lake and Marchant (1990) provide an ecological perspective. They argue that riparian zones are an essential source of food and debris, and as a consequence are critical to stream function. For example, they state that the production of organic matter is a critical source of detritus for many aquatic invertebrates, while riparian vegetation provides harbour for many arthropods, some of which fall into streams, constituting another major food source. Consequently, tree species planted for this purpose should be native rather than exotic as natives are more inclined to provide a consistent food source throughout the year.

Mackenzie and Hairsine (1996) compared the spatial distribution of flow and flow velocities for two separate buffers (grass filter strips and near natural riparian forests) in the catchment of the Tarago Reservoir, Victoria. From their study they concluded that:

A grass filter strip has been shown to result in slower, more uniform overland flow in comparison with a surface formed under a riparian native forest. (p. 211)

More detailed results are provided by Hairsine (1996) from a similar study in the same catchment:

Dense grass filter strips were found to have sediment trapping efficiencies of greater than 95% for a relatively high intensity sediment source. These results were relatively high compared with other studies. This was attributed to the high input load and the dense and near-uniform nature of the grass in the strip.

Near-natural riparian forest, predominantly litter with sparse understorey shrubs and woody debris, was found to have trapping efficiencies greater than 90% for a range of sediment-laden inflows. The sediment trapping efficiencies of both buffer types were found to diminish slightly with increasing water flow, though the results support the overall effectiveness of these buffers as measures to lessen the downstream impact of intense land use. (p. 206)

In their review, Hairsine and Prosser (1997) found that the effectiveness of grass buffer strips, strategically placed to reduce the movement of sediment and nutrient, highly variable. In the Murrumbidgee River catchment, the authors suggest that perennial grasses can prevent future expansion of gullies by protecting the unchannelled surface from erosive forces and by stabilising the gullies themselves. Such grasses can also enhance in-stream water quality by trapping sediments and nutrients. Hairsine and Prosser report that the removal of nutrients from solution varies and:

is a function of the ability of the grass strip to detain runoff for long periods, typically hours to days ... Only with such long detention times are nutrient transforming processes such as denitrification, or plant uptake, significant. Clearly, infiltration of large portions of the overland flow into the soil within the filter strip is essential for these processes to be of consequence. (p. 12)

Another study by McIvor et al (1995) on the influence of pasture management (sowing introduced species, timber treatment, clearing and cultivation, stocking rate) on runoff and soil movement on a neutral red duplex soil at Cardigan, near Charters Towers concluded:

Runoff and soil movement varied widely between years and pasture systems. Ground cover was an important variable influencing both runoff and soil movement and can be used for a management guideline. Managers should maintain at least 40% cover but this level would still allow large losses of suspended sediment in large events. Cover can be increased by improving herbage production (sowing introduced species, fertiliser application, timber treatment) or reducing animal consumption (lower stocking rates). (p. 63)

Removing significant amounts of nutrient from overland flow should not be an impossible task. For example, recent work at 'Flushing Meadows', an experimental site near Wagga Wagga in New South Wales, suggests that, with careful management, even sewage effluent can be 'cleaned' by using it to irrigate tree plantations, thereby reducing the flow of pollutants into inland rivers (Myers et al. 1995).

Washusen and Reid (1996) assert that the effectiveness of riparian vegetation as a buffer depends on the volume and rate of overland flow. They suggest that:

Since the land close to drainage lines and streams is often the most productive, strips of about 20 metres might be reasonable with drainage lines running into the waterways also fenced and revegetated. (p. 63)

Cullen and Lake (1995) note that:

Rivers are unusual ecosystems in that there is a movement of water mass and energy down the river. Consequently, impacted areas can often recover once the cause of degradation is removed since propagules arrive from upstream and can recolonise the impacted area. (p. 122)

2.4.3 Riparian vegetation to stabilise stream banks

Vegetation has been used historically for stream bank erosion control, often to supplement structural works (Frankenberg 1992). Unfortunately, exotic vegetation has been used predominantly in the past. For instance, Frankenberg (1992) recalls that the standard procedure was to plant willow sticks, as they were often easy to obtain and grow and could quickly create a solid hedge which could stabilise a bank very effectively. She states that it is only more recently that the disadvantages of willows have been recognised.

According to Frankenberg (1992):

Generally when vegetation is proposed for river bank planting, trees are the first plants mentioned. In fact, the semi-aquatic herbaceous species such as reeds and sedges are the most important and effective plants for this purpose. These are the plants which actually protect the soil from the erosive force of the water. Much of the success attributed to tree plantings is in fact due to the fencing of the site which enables the herbaceous species to grow. (p. 140)

Marshall (1990) and Harrison (1993) caution that the control of stream bank erosion requires a solid understanding of stream processes and flood flows, as it is a complex problem. Harrison suggests that well-intentioned tree planting in the wrong place can often accelerate the erosion process. For instance, Marshall (1990) states that trees located in and along the stream can exacerbate erosion problems by blocking the channel or by diverting and concentrating flows. Marshall suggests that trees should not be planted in locations where they are likely to either restrict flow or catch debris. He warns that the place most susceptible to erosion is often the base of the embankment on the outside of the bend.

However, Marshall (1990) does concede that in some circumstances:

Trees can be used to strengthen the banks of streams and management of existing trees and a well planned planting may be practical erosion control options. (p. 374)

Furthermore, Frankenberg (1992) notes from her experience on the Murray River that the most stable bank conditions are characterised by a combination of reeds, shrubs and trees that are excluded from grazing, so that the reeds can grow over the top of the bank. As such, she asserts that:

A similar combination (of vegetation), with local tree and shrub species, and with the addition of sedges and rushes, could provide long term bank stability on most rivers and streams. (p. 144)

Howell et al. (1993) have expressed a similar view based on a major geomorphological study of the Hawkesbury-Nepean River. They found:

... a direct correlation between density of vegetation (tree) coverage on the banks and long-term erosion. It was found that the majority of the eroding banks were sparsely vegetated, while the majority of stable banks were densely vegetated with little change in the vegetation cover of the medium-term. (p. 261; citations omitted)

2.5 Biodiversity

2.5.1 Overview of the problem

It is difficult to assess the current level of biodiversity and the threats presented by ongoing agricultural and other activities. Changes in the threatened and endangered species listings are one indication but they may reflect perceptions more than reality. Perhaps the best reference point is the area of relatively undisturbed habitat. As table 2.6 suggests the area of forested habitat has decreased considerably since the settlement of Europeans in Australia.

Table 2.6 Change in the area of major forest vegetation types since European settlement 1990

Structural form	Forest type		Natural area	Present area	Change	Biomass
	Height m	% cover	10 ³ ha	10 ³ ha	10 ³ ha	t ha ⁻¹
Tall closed forest	>30	>70	100	5	-95	450
Tall open forest	>30	30.0–70.0	6 200	5 100	-100	279
Closed forest	10–30	>70.0	3 700	3 400	-300	356
Open forest	10–30	30.0–70.0	54 700	27 400	-27 300	272
Woodland	10–30	10.0–30.0	100 300	61 400	-38 900	150
Open woodland	10–30	<10.0	17 400	40 200	22 800	55
Low closed forest	<10	>70.0	800	200	-600	300
Low open forest	<10	30.0–70.0	3 300	3 400	100	200
Low woodland	<10	10.0–30.0	57 100	45 200	-11 900	100
Low open woodland	<10	<10.0	147 600	158 300	10 700	50
Tall shrubland	<2	10.0–30.0	113 800	74 100	-39 700	22
Tall open shrubland	<2	<10.0	136 300	162 300	26 000	10

Source: ABS (1996).

One of the most widely accepted definitions of biodiversity is that provided by Wilson (1992). He defines biodiversity as:

The variety of organisms considered at all levels, from genetic variants belonging to the same species through arrays of species to arrays of genera, families and still higher taxonomic level; includes the variety of ecosystems, which comprise both the communities of organisms of particular habitats and the physical conditions under which they live.

However, as outlined by Williams et al. (1996), most definitions of biodiversity are confounded by the fact that they simply become a synonym for ‘all life’, plus all their associated physical conditions. For this reason, Doherty et al. (in press) advise that working definitions are required to specify the units used in its measurement. They note that biodiversity is commonly broken down into three units of measurement: ecosystem, species and genotype.

With regard to ecosystems, they are generally considered to comprise some amalgam of habitats, the species within them, ‘communities’ within them and importantly the ecological processes occurring within them (Wilcove and Blair 1995). But according to Doherty et al. (in press) the utility of ecosystems as a measure of biodiversity is confounded by the:

... looseness of definitions and the seeming inability to reach consensus on what they are in an operational sense. (p. 8)

As such, Doherty et al. (in press) suggest that due to the relative ease at which:

... different species can be recognised, the clear functional roles identified for many species and the effectiveness of species as units of management

that species are:

... ideal units for the measurement of biodiversity. (p. 9)

Nevertheless, broader aggregations are often needed for regional-scale assessments. For example, the CAR (comprehensive, adequate and representative) reserve system criteria, developed for use during the regional forest agreement process, are applied at the forest type not species level. Considerable use is made of species information, but for many important groups, such as fungi, beetles, mites, collembola and bacteria, most species have not yet been described, let alone surveyed across their natural distributions.

The role of genetic diversity as a basic measure of biodiversity, while clearly important, has been ruled out by many as too difficult and costly to use (Moritz 1994). Doherty et al. (in press) state that the conservation of genetic diversity should be considered as a subset of the notion of conserving species diversity by conserving species across their range, especially in instances where data on genetic variation are currently lacking and where species taxonomy are currently being revised.

In terms of conserving biodiversity, Hobbs (1993) states that there are three main ways in which revegetation can be useful. These include the provision of buffer strips around existing remnants, the provision of corridors to increase connectivity between existing remnants, and the provision of additional habitat. However, in saying this, Hobbs (1993) also acknowledges that there is a fourth, although somewhat indirect, method by which revegetation can conserve biodiversity and that is through its role in reducing current levels of degradation to the agricultural landscape as a whole. These methods are now discussed in more detail.

2.5.2 Buffer strips

Hobbs (1993) states:

... buffer strips around existing remnants could protect the native vegetation from the harmful effects of external factors such as nutrient and particulate inputs, wind damage and weed invasion. (p. 31; citations omitted)

The rationale behind the use of buffer strips is that:

... such strips effectively move the edge of the remnant, and hence the adverse 'edge effects', further out. If these strips are made up of native species, they may also extend the habitat area, but the sheltering effect could be achieved by using any species which create a barrier. Thus there is the opportunity to establish strips with timber or other tree-product value. (Hobbs (1993); p31)

According to Hobbs (1993), the specifications for the buffer strip will vary depending on whether the objective is to ameliorate biotic or abiotic impacts from the surrounding landscape. For instance, even very large strips will not reduce the impact of major herbivores (for example, rabbits and sheep) and predators (for example, foxes and cats). Yet a relatively thin strip may be effective in improving the downwind microclimate for crops and pastures. Abel et al. (1997) have implied that the use of buffer strips is one of the more effective revegetation methods for conserving plant diversity in existing remnants due to its potential role in mitigating edge effects.

2.5.3 Corridors

A comprehensive review of the role of corridors in the conservation of biodiversity, focusing on agricultural areas, has been prepared by Wilson and Lindenmayer (1995), while Saunders and Hobbs (1991) provide a collection of papers devoted to the issue, both in the Australian context and internationally. Wilson and Lindenmayer (1995) acknowledge the deficiencies in experimental design of many corridor studies (as noted by Nicholls and Margules 1991), but contend that their review serves to highlight the potential role of corridors in enhancing species persistence in fragmented landscapes.

Wilson and Lindenmayer (1995) state that from a functional point of view:

... the effectiveness of corridors is gauged by their ability to facilitate dispersal and recolonisation of patches within a patch-corridor-matrix landscape. Thus, the assessment of corridor effectiveness must be based on an evaluation of the corridor's role in establishing and maintaining connectivity between wildlife populations. (p. 53)

According to Wilson and Lindenmayer (1995) considerable research effort has been directed towards the identification of factors which may influence the use of corridors by animals. They suggest that these factors can be grouped into four main categories: (a) landscape spatial structure; (b) corridor dimensions; (c) habitat suitability; and, (d) autecology of animal species and population dynamics.

Landscape spatial structure

Landscape spatial structure is defined by Wilson and Lindenmayer (1995) as the spatial relationship between the components in a landscape, which may include habitat patches, corridors and the surrounding matrix. These authors have identified four components of landscape spatial structure which may influence the effectiveness of wildlife corridors.

Location in the landscape

Wilson and Lindenmayer (1995) state that the:

... position and location of habitat patches and corridors in the landscape influences their use by fauna. (p. 26; citation omitted)

Furthermore, they assert:

It is important that a variety of topographic elements are captured in a corridor network system to provide a range of habitat types and access to resources throughout many parts of the landscape. (p. 27; citations omitted)

For instance, Claridge and Lindenmayer (1994) have highlighted that corridors confined to gullies may be inadequate for the conservation of those species which rely on other parts of the topographic sequence for food and shelter. As an example, these authors suggest that in general:

... the preference of *I. obesulus* (Southern Brown Bandicoot) for drier slope and ridge habitats, and the preference of *P. nasuta* (Long-nosed Bandicoot) for wet areas such as along watercourses, occurs throughout the geographic ranges of these species. (pp. 302–303; citations omitted)

Claridge and Lindenmayer (1994) support the view that in the case of timber production forests, a range of corridor types are required (for example, some in gullies, other on

midslopes and ridges), but most importantly, corridors are needed to connect these different parts of the landscape.

While this conclusion has been drawn from the results of studies conducted in the forests of southeastern Australia, it serves to illustrate that the ability of a corridor to satisfy the dispersal and habitat requirements of a broad range of species will ultimately depend on the diversity of topography that the corridor can provide.

Merriam (1991) states that movement between patches are necessary for the survival of a metapopulation of several patch populations that functions as a single demographic unit. He cites modelling and field studies showing that interpatch movements between populations of the white-footed mouse (*Peromyscus leucopus*) improved metapopulation survival, as did the degree of connectivity: metapopulations most likely to survive were those with the greatest degree of connectivity between patches.

Habitat patch size

As noted by Wilson and Lindenmeyer (1995) the effectiveness of wildlife corridors:
... may be influenced by variation in the size of the patches being connected, and hence, the animal populations being connected... (p. 28)

They suggest that the implications of the relationship between patch size and the size of animal populations for wildlife corridors are:

- (1) large corridors may support a greater number of species and larger population; and (2) it may be important to consider the impact on animal populations of connecting large patches to larger patches, large patches to smaller patches and smaller patches to other smaller patches (p. 28)

Doherty et al. (in press) advise that species diversity increases as the size of the sampling area increases: thus larger areas contain more species. These authors acknowledge that this relationship has been known for decades, but suggest that the reason for it has not yet been confirmed. They state that:

... it seems likely that the true explanation for the relationship is a combination of two hypotheses: the area *per se* hypothesis, which suggests that the relationship is a result of a dynamic equilibrium between immigration and extinction rates which are determined by area and isolation; and the habitat heterogeneity hypothesis, which states that the increased areas is due to the greater number of different habitats available. (pp. 44-45)

Boundary/edge effects

Boundary effects are defined by Wilson and Lindenmayer (1995) as:
a result of structural differences in vegetation which influence animal behaviour at the edges of a habitat patch or corridor. (p. 28)

However, according to Taylor (1991), not all Australian landscapes are characterised by a sharp contrast between the boundaries of the remnant vegetation and the matrix. Given this, Wilson and Lindenmayer (1995) suggest that boundary effects, along with the impacts of fragmentation and landscape modification, may vary with the extent of this contrast.

Wilson and Lindenmayer (1995) claim that edge effects are major potential disadvantages of corridors, as they can impact significantly on:

... both corridor effectiveness and, through habitat deterioration, the long term integrity of small or narrow remnant vegetation patches. (p. 23)

According to Abel et al. (1997) remnants that are long and thin have significantly more edge relative to their area and as a consequence, are much more susceptible to the negative impact of edge effects, such as increased nest predation and weed invasion. These traits are particularly prevalent in riparian vegetation and corridors which are more vulnerable to these edge effects because of their linear characteristics.

As such, Abel et al. (1997) advise that:

Patches should have the least possible edge, and linking vegetation should be as wide as practically feasible. (p. 68)

Surrounding land use and matrix suitability

According to Wilson and Lindenmayer (1995) the nature of the surrounding land use matrix can be characterised by:

... a range of attributes including vegetation type, patch density, mesh size, (the average distance between corridors and patches), land use and the types of disturbance which occur. (p. 29)

These authors suggest that the:

... type of land use or source of disturbance in the neighbouring matrix can influence the composition and abundance of wildlife populations in remnant patches and wildlife corridors. (p. 30; citations omitted)

Corridor dimensions

Wilson and Lindenmayer (1995) state that corridor dimensions include attributes like the shape, width, length and size (or area). As shape and size have been dealt with previously, the focus here will be on width and length.

Width

According to Wilson and Lindenmayer (1995), several studies have demonstrated that corridor width influences species richness, dispersal and the shape, number, and size of home ranges. For instance, they cite a study by Cale (1990) which shows that the mean width of vegetation in woodland road reserves of Western Australia is positively correlated with average bird species richness. Saunders and de Rebeira (1991) also report a positive correlation between the number of bird species dependent on remnant vegetation and the width of corridor in the West Australian wheatbelt.

Harris and Scheck (1991) point out that the width of a faunal dispersal corridor must be appropriate to the scale of the phenomenon being addressed. For example, under a scenario in which large scale, rapid climate change occurs, the movement of entire species assemblages may be required to ensure their survival. In such situations, and/or if the faunal dispersal corridor is expected to function over decades:

then the appropriate width must be measured in kilometres. (p. 204)

Wilson and Lindenmeyer (1995) advise that basic principles regarding prescriptions for the width of corridors are derived from the premise that wide corridors are more effective than narrow ones. They state that this is because:

1. there is greater interior / edge ratio;
2. a greater variety of habitat types and quality may be captured; and
3. they have a higher probability of supporting resident fauna populations. (p. 32)

Length

Wilson and Lindenmeyer (1995) note that:

The length of a wildlife corridor is essentially the maximum distance an organism must move from one habitat patch to another (assuming it moves within the corridor) ... It can be assessed by corridor length, number and severity of gaps or barriers and the presence of alternative pathways ... Optimal corridor length is also a function of species-specific behaviour and habitat quality. (pp. 31-32; citations omitted)

Habitat suitability

According to Wilson and Lindenmeyer (1995) the suitability of corridor habitat (that is, the availability of essential resources, such as food, shelter, breeding sites) can influence the probability:

1. an animal will move through a corridor;
2. mortality during movement through a corridor;
3. the ability of an animal to use the corridor as a place to live. (p. 34; citations omitted)

These authors suggest that some of the major factors influencing habitat suitability are both vegetation structure and plant species composition. But they point out that it may take many years for suitable habitat to sufficiently develop. For example:

... it may take 5-10 years for understorey plant species to provide resources for nectar-feeding birds. The needs of arboreal marsupials and cavity nesting birds may not be met until hollows in trees develop (for example, in trees > 50-500+ years old). (p. 25; citations omitted)

and as such, some types of rural plantings:

may never provide suitable habitat for many species of wildlife. (p. 25)

Autecology of animal species

Wilson and Lindenmeyer (1995) note:

The life history and other attributes of the species targeted for conservation may influence the effectiveness of corridors. Some of these attributes include; diet; social organisation; dispersal behaviour; breeding strategies; dispersal capability; home range size; and species interactions. However, it cannot be assumed that the autecology of a species is the same in all landscape types. (pp. 34-35; citations omitted)

For instance, it is suggested that the dynamics of species-habitat interactions may change depending on the configuration and position of a corridor in the landscape.

2.5.4 Increased habitat

According to Saunders and Hobbs (1995), the remaining native vegetation in Australia is insufficient to retain functioning ecosystems which will maintain viable faunal and plant populations in the long term. They advocate increasing the extent of areas useful for conservation.

Hobbs (1993) states that:

unfortunately there is very little information on the extent to which faunal species will recolonise or use revegetated areas. (p. 32)

He suggests that ultimately:

the attractiveness of revegetated areas to particular species will depend on the levels of resources and /or shelter provided, coupled with their distance from existing habitat. (p. 32)

According to Hobbs (1993) there are no clear principles for designing revegetation for conservation, although Saunders and Hobbs (1995) offer some simple guidelines for habitat reconstruction. Hobbs (1993) asserts that the ultimate goal should be to restore structure and function similar to that of existing native vegetation. He acknowledges that revegetation anywhere in the landscape is beneficial, although he believes there are several reasons why revegetation should be preferentially located next to an existing remnant. For instance:

Firstly, the revegetation will effectively increase the size of the remnant and thus may alleviate some of the problems caused by smallness (for example, small population sizes, minimum critical areas for animal territories). Secondly, fauna will have less distance to travel to colonise the revegetated area than if it were isolated. Thirdly, juxtaposition with a remnant may allow native plant species (and other ecosystem components) to recolonise naturally. Finally, management of a single larger area (including fencing) will be cheaper than the maintenance of two small areas. (p. 32)

2.5.5 Landscape stabilisation

According to George et al. (1996), the problem of salinisation in southwestern Australia is not only removal of agricultural land from production:

If current (groundwater) recharge rates remain unchanged, we estimate that up to 25% of many landscapes, and as much as 40–50% of some specific regions (most of the lower slopes and valley floors) will become salt affected within the next century. All (native vegetation) remnants occupying those areas, along with adjacent lakes and wetlands, and most riverine or estuarine lakes and wetlands, will either decay or be permanently altered. (p. 13)

This is also recognised by Hobbs (1993) who suggests that a long term solution is to restore the hydrological balance across the entire landscape through strategic placement of areas of revegetation. Thus Hobbs (1993) argues:

... even if the revegetation has no nature conservation value per se, but helps to stabilise the overall landscape, it will be performing a valuable function in preventing the eventual complete loss of the existing remnant system. (p. 33)

2.6 Implications for indicator development

2.6.1 Salinity control

Revegetation of catchments with trees and shrubs is widely promoted as a solution to the problems of dryland salinity, with retention of native vegetation as a preventative measure. The aim of revegetation and maintenance of remnants is to minimise recharge and maximise discharge of groundwater.

Effectiveness as a solution

As part of the *National Farm Tree Survey* (Nicholls and Dobbie 1996) farmers who had planted trees to ameliorate dryland salinity problems were asked to assess the effects. Out of

a total of 569 farmers 48 per cent reported an improvement, 22 per cent observed no improvement and 28 per cent indicated that it was too early to make an assessment.

Tree planting in recharge locations can contribute to the control of dryland salinity. Trees use more water from deeper in the soil profile throughout the year than annual crops and pastures, reducing the amount of water reaching the groundwater table. As the accession of water to the ground watertable is the underlying cause of the problem, any reduction in groundwater recharge will contribute to salinity control. Whether this effect is significant enough to halt or reverse the process of salinisation depends on the extent of the area that is planted to trees and the location in which they are planted.

As far as water use in water-limited environments is concerned, species of trees used may be unimportant. Nevertheless, differences between species in such attributes as root architecture and depth, salt tolerance, canopy structure, leaf area, and physiological features may be important. Water use per tree is usually greater in open grown trees than in trees growing in a forest situation.

Certain perennial pastures such as lucerne may also be effective in increasing water use, although these have few of the shade, shelter, aesthetic or biodiversity benefits of native trees.

Tree planting in discharge areas is not a solution to dryland salinity, but rather a 'band-aid' approach to the problem. Tree planting in these areas can potentially minimise the areal expression of saline scalds, but their effectiveness depends on the soil texture of the discharge zone, depth to watertable and the salt tolerance of the species selected.

Lower slope and discharge plantings tend to cause a localised reduction in watertables beneath revegetation, whilst wide spaced plantations will significantly reduce watertables under pasture as well. For salinity control in hill country in Victoria, recommended strategies include the establishment of high density plantations on small strategic areas of high recharge and low density woodlands on extensive areas of high recharge or those areas not suited to perennial pastures.

It is unwise to extrapolate or even generalise from results obtained from water use experiments due to the inherent complexity of the salinisation process, and the absence of detailed knowledge in new areas (for example, local hydrogeological constraints).

Models of the process

Modelling may allow predictions about how long it will take for revegetation to exert control over rising watertables. However, it is probable that the speed of the response is dependent on the area that is planted, the location planted, the species planted, and their structural and physiological features.

At present all models of catchment hydrology suffer from a general weakness of not being able to link the movement of sediments, nutrients and pollutants through the catchment, with farming systems.

Rehabilitation of remnants of native vegetation to their pristine condition gives a significant improvement in saline seepage and increased streamflow.

2.6.2 Soil conservation

There appears to be three main processes by which vegetation can help control soil erosion. The first is the protection surface cover provides against the erosive forces of wind and water. The second is the provision of an 'umbrella' function protecting soil from the direct impact of rain. However, such cover may actually increase the energy per mm of rainfall available for erosion by increasing drop size where they leave the 'umbrella.' The third process involves the amelioration and enhancement of soil properties.

Effectiveness as a solution

Benefits were reported by 69 per cent of farmers who had planted trees to reduce wind erosion and 76 per cent of those who had planted trees to reduce gully erosion (Nicholls and Dobbie 1996).

The planting of trees alone may not be sufficient to control water erosion. For tree plantings to be effective, they also need to contain shrubs and ground cover plants, as well as litter, to protect the soil surface from raindrop splash and to obstruct overland flow. Trees planted to reduce water erosion are also likely to be effective at reducing wind erosion, provided that they follow some basic design principles, such as being oriented at right angles to the prevailing winds.

The principal determinants of the effectiveness of trees planted to control wind erosion are the height and length of the windbreak. The height of the windbreak determines the distance to which the sheltered effect extends into the paddock, while the length of the windbreak determines the total area sheltered. Management of the windbreak itself may also play a role in determining its effectiveness.

Models of the process

Models of the biophysical processes contributing to soil loss, and structural decline are used in a variety of ways. They have been integrated into yield estimations such as those made by the Agricultural Production Systems Research Unit using APSIM, an agricultural production simulation model (see chapter 4).

2.6.3 Improving water quality

Riparian vegetation is critical to the efficient function of aquatic ecosystems. Native species should be selected for planting ahead of exotics as, unlike deciduous exotics, natives provide a consistent habitat for aquatic flora and fauna throughout the year.

Effectiveness as a solution

Trees may be of limited value in buffering streams and rivers from point source pollution, but are more effective in reducing diffuse source pollution. Trees alone are generally inadequate, as they need to be used in combination with shrubs and groundcover vegetation in order to

obstruct and filter overland flow. In some circumstances trees may promote erosion relative to other groundcover strategies.

Trees planted for bank stabilisation are not sufficient for land and water conservation. All structural elements are necessary, therefore groundcover such as grasses, sedges and rushes should be an important component of revegetation programs.

There is considerable potential for plantations irrigated with effluents to reduce the pollution contributed to inland rivers by human bodily wastes.

2.6.4 Conservation of biodiversity

Protection of existing habitat and increasing areas of potential habitat are key to conserving biodiversity.

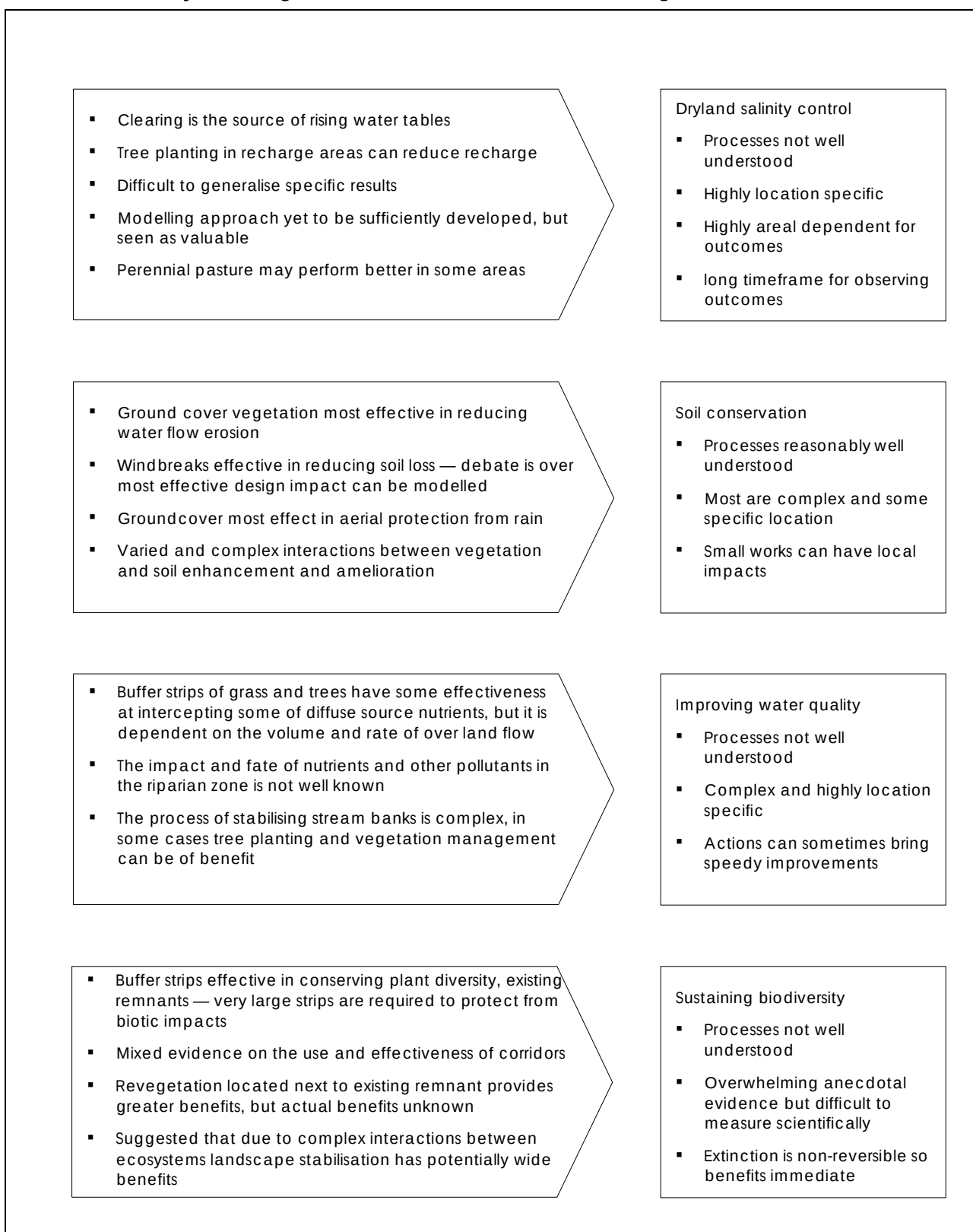
Effectiveness as a solution

Buffer zones are highly effective in protecting habitat from abiotic sources of disturbance, but less so from biotic sources.

The issue of revegetation providing landscape linkages or corridors to aid the movement of the native biota is a vexed one. The widespread general acceptance of the role of corridors as a conservation strategy does not reflect the scientific uncertainty about their contribution to the conservation of biodiversity. At present there is no unequivocal evidence to show whether revegetation will be of any significant benefit to nature conservation. Given that the information about the effectiveness of corridors is incomplete and that there are potentially negative effects of corridors on some species, land use planners and managers should not view corridors as an all encompassing solution to conservation problems associated with fragmentation and human modification of landscapes.

Chart 2.2 summarises the findings.

Chart 2.2 **Summary of findings: effectiveness of actions in delivering outcomes**



3 Biophysical processes — sustainable production

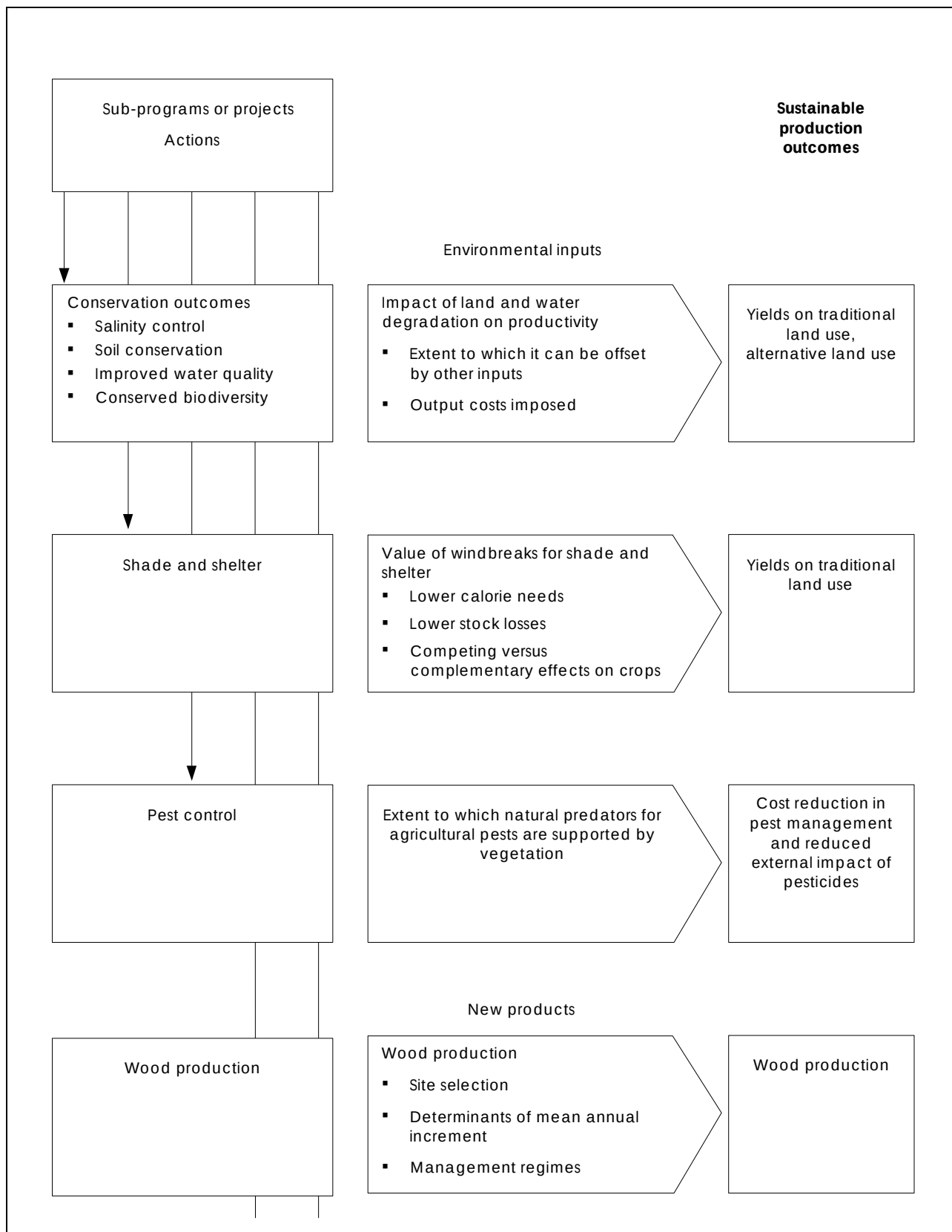
This chapter focuses on the biophysical processes that deliver sustainable production. As outlined in chart 3.1, it is divided into three main sections: environmental inputs into production; new products for sustainable production and off-site production effects. The first section deals with the process by which the conservation outcomes, shade and shelter, and habitat for natural predators impact on agricultural productivity. The second part deals with new products that contribute to sustainability of agriculture. These are wood production and new non-wood production. Carbon sequestration can be thought of as off-site effect as it is the reduction in carbon dioxide emissions that is of value. But it is also a third type of new product that may become an important component of sustainable agriculture in the future. The other major off-site effect is damage to infrastructure.

Whether these outcomes relate to developing sustainability depends partly on the definition of sustainability and off-site production effects. Before commencing these sections, it is important that we develop an understanding of what is meant by the term ‘sustainable’.

3.1 Defining sustainability

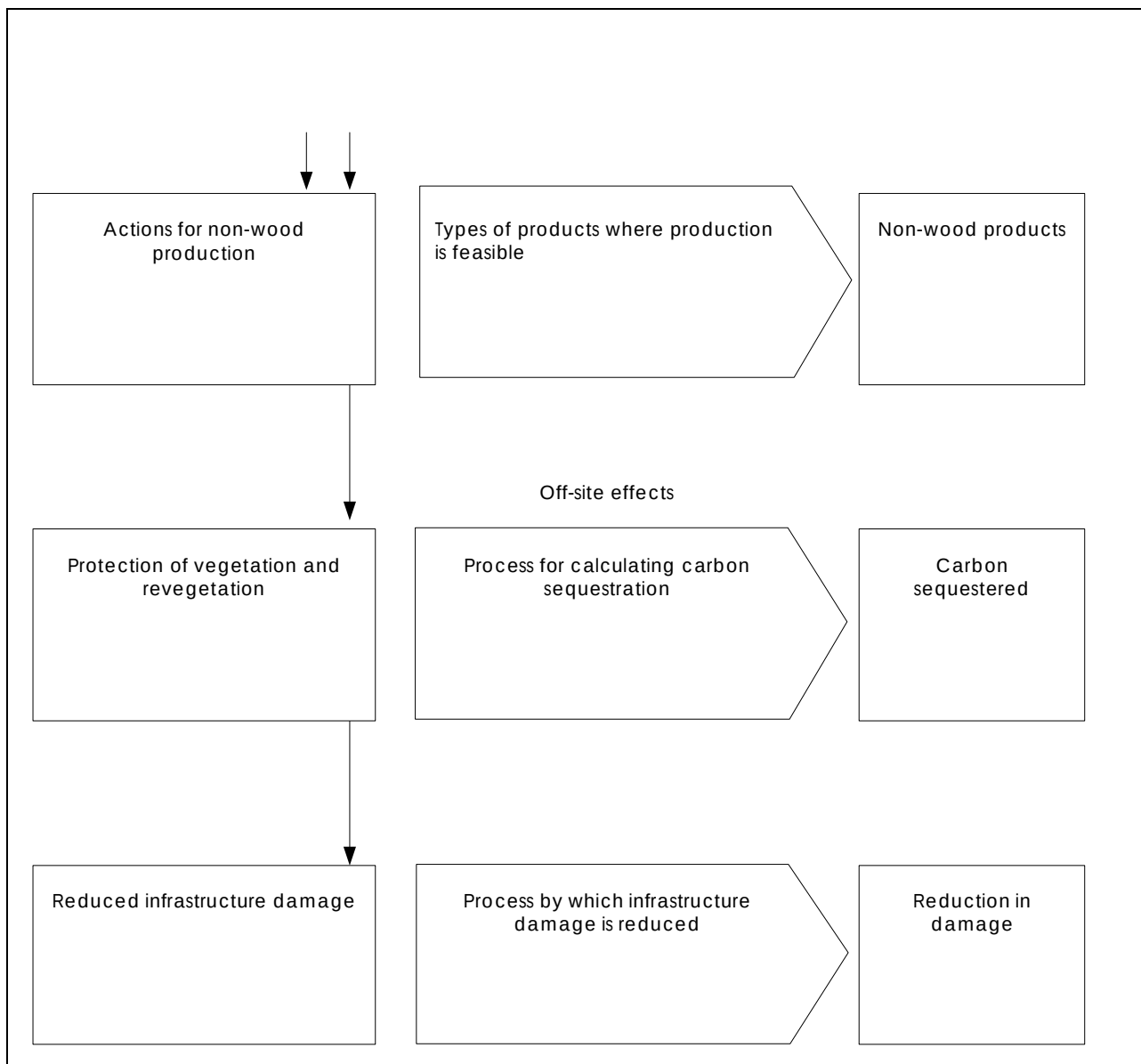
According to Lefroy and Hobbs (1992) achieving sustainability in agriculture involves simultaneously satisfying ecological, economic and social requirements. They also suggest that it is possible to define the required economic and social conditions relatively easily in terms of the viability of the regional economy and the support of rural populations. However, the ecological conditions that need to be met are more difficult to define. Nevertheless, Lefroy and Hobbs (1992) contend that there is general agreement on the broad aspects of ecological sustainability and that these relate to the cycling of matter in the form of water and nutrients, the flux of energy, and the role of species richness in the dynamics of the biotic component.

Chart 3.1 Biophysical processes for delivering sustainable production



(Continued on next page)

Chart 3.1 **Biophysical processes for delivering sustainable production** (continued)



The Standing Committee on Agriculture and Resource Management (SCARM; formerly SCA) have defined agricultural sustainability as:

The use of farming practices and systems which maintain or enhance:

- the economic viability of agricultural production;
- the natural resource base; and
- other ecosystems which are influenced by agricultural activities. (SCA 1991, p. 4).

But according to Lefroy and Hobbs (1992), any definition of agricultural sustainability is meaningless unless spatial and temporal scales are defined. This is because different constraints tend to dominate at different scales. For instance:

At the farm level, the dominant constraints are economic and the overriding goal is the survival of the farm business over a time scale often expressed in units of several generations of the farm family. ... At the landscape level, the dominant constraints are ecological and the

goal is maintenance of the life-supporting capacity of the catchment or landscape unit over a time scale considerably longer than units of several human generations. (Lefroy and Hobbs 1992, p. 22-23)

However the problems of defining sustainability are not confined to the agricultural sector. Ferguson (1996) considers sustainable forest management a logical extension of the principle of sustainable development as defined by the Brundtland Commission:

...that current needs are to be met as fully as possible while ensuring that the life opportunities of future generations are undiminished relative to the present. (p. 110)

He asserts that such a definition provides little specific guidance operationally and considerable scope to manoeuvre. Therefore given the above discussion, it is not at all surprising that Ferguson (1996) regards sustainability as:

... a ritualistic symbol or icon of some desired but ill-defined future (p. 110)

It is not a task here to define sustainability. For our purposes, we consider improving yields on traditional activities by improving natural resource management, introducing new products with greater long term economic and ecological viability, and reducing costs imposed by land degradation contribute to sustainability, however defined.

3.2 Benefits from conservation outcomes

3.2.1 Dryland salinity

In chapter 2 we discussed the environmental outcomes of dryland salinisation, but what are the implications of salinisation for sustainable production. According to Nulsen (1992), the capital value of the land lost to dryland salinity in Australia is \$450 million and the gross annual value of lost production \$100 million. However, these figures are based on the assumption that salt affected land has no capital value and no production value. This is not necessarily true.

Productive use of saline land

The issue of maintaining productivity on salt affected land is being addressed by a National Program titled the Productive Use and Rehabilitation of Saline Land (PURSL) which is a collaborative effort of the States and the Commonwealth (Barson and Barrett-Lennard 1995). The research conducted within this National Program can be divided into two major groups. The first involving the use of grasses and shrubs as forage for grazing animals, and the second, the use of trees and shrubs for wood and non-wood products.

With respect to forage for grazing animals, Barson and Barrett-Lennard (1995) report that a number of perennial halophytic grass and shrub species are currently being grown on saline soils in eastern and Western Australia. However, despite the fact that these grass and shrub species are being grazed by animals, they suggest that their value as forage is relatively low, due largely to the high salt concentrations in their leaves. They concede that better quality forage may be possible using salt tolerant annual species, but their long term sustainability may be questionable as they use little water in summer and do not contribute to watertable control.

According to Marcar and Crawford (1996), tree growing in a variety of farm forestry systems can be a productive use of saline land. However, they go on to assert that in order to obtain maximum production from saline land it is:

...vital to choose the correct tree species, land preparation and planting techniques and tree growing systems. (p. 34)

While Marcar and Crawford (1996) acknowledge that trees, shrubs and grasses can be planted on saline discharge areas (often referred to as seeps and scalds). They suggest that trees planted adjacent to these areas will have better survival, growth and water use than those planted on the discharge area. This is due to more favourable soil physical and chemical conditions, as well as the greater availability of less saline groundwater.

It is important to note that all species of current or potential commercial plantation interest are non-halophytes and have, at best, only moderate salt tolerance (Marcar and Crawford 1996). As such, these species would be more suited to locations above, rather than within, saline discharge areas. Marcar and Crawford (1996) advise that:

...the most likely products from woodlots or other agroforestry systems on moderately to highly saline land in Australia is firewood. (p. 38)

Other non-wood products, such as leaf oils and tannins, could also prove potentially viable, but more research is required to ascertain their suitability as discharge plantings.

Reducing production losses through salinity control

The preceding section has demonstrated that it is possible to obtain production from saline land, however it is worth remembering that discharge planting's only address the symptoms of dryland salinisation and not the cause. It could therefore be argued, that the planting of recharge areas (which addresses the cause of dryland salinisation) has the potential to reduce losses in existing production by slowing, halting or reversing the encroachment of saline seeps and scalds. According to Hook (1992) the proportion of farm income that is lost through reduced agricultural productivity will depend on the size of the property, the productivity of affected land before salinisation and the productivity of the remaining land.

Emery (1988) has advised that the average annual cost of lost production due to dryland salinity in New South Wales is \$100 per hectare. But a more specific study conducted by Carlos (1991^a) in the upper Lachlan Catchment has shown that this cost may vary considerably. She found that the value of lost production on farms located on Silurian volcanics could range from \$250 per hectare for Canola, to \$44 per hectare for Triticale. On farms situated on Ordovician sediments the cost could range from \$117 per hectare for beef cattle to \$58 per hectare for 24 micron wool.

3.2.2 Soil degradation

Williams (1991) states that:

Land degradation is so often the result of a failure to examine the whole farming system in the context of the hydrological or nutrient cycle in which it is cast. Progress toward sustainable agricultural practice will only be made while the implications of these practices are viewed and examined as part of the regional ecosystem. Agricultural scientists and the farming community must think beyond the farm gate to see how the farm is integrated into the catchment and the landscape as a whole. (p. 39)

This point about regional context is particularly relevant to the more insidious forms of land degradation such as dryland salinity. However, it appears that the main thrust of Williams' assertion is that we require a new holistic way of looking at the farming system, with particular attention focused upon sustainable integration of agriculture with the natural resource base. For instance, Williams notes that:

Erosion control in cropping land has depended to a large extent on engineered structures such as contour banks and grassed waterways. In future, more sustainable farming practices will require much higher infiltration rates, rougher surfaces, more surface detention storage and deeper, but lower, velocity overland flow. The need for alternative methods of erosion control that can handle the catastrophic events will be essential. The nutrient loss through erosion is a major loss that a 'sustainable' farming system cannot afford. (p. 39)

What Williams (1991) seems to be suggesting is that we need to shift away from quick-fix solutions to many soil degradation problems, such as contour banks and grassed waterways, and move towards more ecologically-minded long term solutions which address the causes of dysfunction in agricultural ecosystems.

The focus of chapter 2 was to outline the biophysical processes by which trees, shrubs and grasses could be used to deliver environmental outcomes. But with particular reference to soil degradation, what are their role in providing production outcomes? Well, their role would appear twofold; firstly to minimise the loss of soil and nutrients, and secondly, to enhance soil physical and chemical properties.

Controlling soil degradation to reduce production losses

The relationship between erosion and plant production is not straightforward. For instance, Rose (1992) has argued that:

Plant production is affected by many factors other than the loss of soil and nutrients, water availability commonly being of particular importance in the less-humid regions of Australia. Hence, in order to definitively associate a decline in plant productivity with erosion, the influence of other factors needs to be recognised. Often these other factors (such as the amount of plant available water stored in the potential root zone) can themselves be affected by erosion. Thus it is difficult to unequivocally and quantitatively define the reduction in plant production due to soil erosion. (p. 8)

Nevertheless, without knowing the fine detail of the relationship, it may be safely assumed that trees, shrubs and grasses which are effective at controlling erosion are likely to be a positive benefit to production. This is because effective erosion control can not only reduce the amount of land taken out of production, but may also reduce declining production on remaining land, through conservation of ecosystem resources such as soil and nutrients.

Increasing production through enhancement of soil properties

According to Noble and Randall (1998) the effects of agroforestry systems on soil properties and the yields of annual food crops, depend on a number of factors which include:

- the type of agroforestry system;
- the proportion of land area allocated to food crops versus tree crops;
- ecological compatibility of different species used;
- soil and crop management systems used for food crop production; and
- antecedent soil properties and the prevailing climate.

Saffina and Xu (1998) conducted field experiments in the semi-arid tropics of northern Australia to investigate nitrogen cycling in the leucaena (*Leucaena leucocephala*) alley cropping system. They concluded:

...the application of leucaena prunings could substantially increase maize yield and N uptake although some supplementary N fertiliser may be required to achieve maximum crop yield. Maize recovered only a small amount of added leucaena N in the first year. Most of the leucaena residue N was present in the soil and remaining residues after one season. This residue N would be gradually available for plant uptake and subsequent crops. Of course, annual additions of leucaena prunings would appreciably increase the pool of available N over time. Thus application of leucaena prunings could substantially improve soil fertility in the long term. (p. 124)

Therefore, it is possible that production increases can be achieved through the soil enhancing characteristics of some trees and shrubs.

3.2.3 Surface water (on-site)

In a study of the effects of cattle trampling and farm dam sedimentation in the South Gippsland region of Victoria, Lloyd et al. (1996) demonstrate the production benefits of vegetation management. They argue that several American studies have found that where cattle have access to stream banks, subsequent erosion of these bank is due primarily to trampling by cattle and the removal of forage along the waterline. Lloyd et al. (1996) assert that when cattle are excluded from the water's edge, vegetation is able to become well established, thereby stabilising the banks and reducing the impact of fluvial and wave processes. They suggest, that these fluvial and wave processes are equally relevant to farm dam shorelines. Table 3.1 outlines the costs landowners pay for the construction and maintenance of a small farm dam.

Table 3.1 Construction and maintenance costs of a fenced and unfenced farm dam

<i>Initial costs</i>	<i>Unfenced dam</i>	<i>Fenced dam</i>
	\$	\$
Dam construction (20 m X 30 m dam)	800	800
Fencing (5 strand barbed wire)		600
Gravity fed drinking trough		300
Subtotal	800	1 700
Long term costs (90 years)		
Maintenance/dredging	600	
Cost of an algal bloom (livestock losses)	1 000 to > 10 000	50
Maintenance of reticulation system		100
Subtotal	>1600	150
Total (Assuming ten cattle die for the unfenced dam as a result of algal bloom)	>6 400	1 850

Source: Lloyd et al. (1996).

Based on the above calculations Lloyd et al. (1996) conclude:

The known costs of de-silting infilled dams and the potential costs of algal blooms associated with the introduction to the dam of cattle excrement and nutrient-tagged sediments mean that the fencing of farm dams at the time of construction and the provision of gravity-fed stock watering points are economically viable. (p41)

3.3 Benefits from vegetation inputs

3.3.1 Shade and shelter

According to Fitzpatrick (1994) there are many benefits to crops, pasture and livestock that accrue from the shade and shelter provided by trees, but the most significant are a result of reduced windspeed. These may include increased production from crops and pastures, reduced deaths in stock from exposure, and a decrease in energy loss in stock during cold weather resulting in increased production.

Haines and Burke (1993) advise that:

...wind can be very destructive to agriculture in exposed areas. Such effects may be striking (for example soil erosion, unchecked wildfires or loss of stock after a severe cold snap) or they may be more subtle (e.g. increased evaporation leading to greater plant stress and reduced crop yield and pasture growth. The result is reduced farm productivity in the short and long term. (p. 37)

Fitzpatrick (1994) states that:

...the effectiveness of windbreaks depends on the positioning in relation to the prevailing harmful winds, the spacing between breaks, their height, width, length, evenness and permeability. (p. 6)

Bird (1993) has assessed the economic viability of establishing a network of shelterbelts over a wind-swept grazing property in South-Eastern Australia. The results indicate that when 5 per cent of the property is planted to trees in a shelter network the profitability of the farm will be increased in the long term. When 10 per cent of the property is devoted to a shelter network the profitability depends on the discount rate, the farmers labour inputs and the distribution of the trees. Furthermore, it is suggested that at discount rates less than 5 per cent it is better to have 10 per cent of the property in closely spaced belts than 5 per cent of the farm in wide spaced belts. This is due to the more effective shelter provided in the first scenario which is reflected in the increased productivity of the property.

Crop production

As pointed out by Haines and Burke (1993) trees are often perceived by farmers as an impediment to successful dryland cropping because they compete for limited soil moisture and nutrients and occupy what may otherwise be productive land. While there is very little empirical data to persuade farmers otherwise, there is some anecdotal evidence that shelterbelts may increase the yield of certain crops grown on the leeward side. Fitzpatrick (1994) provides further support for this notion, suggesting that wind increases evaporation of water from soil and plants surfaces, therefore:

Shelter that reduces windspeed decreases evaporation. The moisture available for plant growth is increased; therefore the effective rainfall is increased, and this increases plant growth when there is a shortage of available moisture. (p. 8)

Only a handful of Australian studies have set out to quantify this relationship. One of the more recent is that described by Haines and Burke (1993) which was conducted at the Department of Agriculture Victoria's Rutherglen Research Institute during the period between 1990 to 1993. The experiment examined the change in wheat and oat yields at different distances out from two 6m high shelterbelts. One shelterbelt was oriented north-south and the other east-west. Grain yields were measured in 1990 and 1991 and it was found that competition for light and moisture within a distance of 9m (1.5 * Shelterbelt Height) resulted in a reduction in yield. However, grain yields between 9 and 54m out from the leeward side of the shelterbelts increased by 25 per cent (wheat) and 17 per cent (oats) on the south side of the east-west shelterbelt, and by 22 per cent (wheat) and 2 per cent (oats) on the east side of the north-south shelterbelt.

It was concluded that:

... reduction in evaporation appears to be the most important factor associated with shelter at this location, and perhaps for most dryland cropping areas in south-eastern Australia. Moisture that is conserved in the sheltered zone can be used by the plant later in the growing season, particularly during the critical times of flowering and grain filling. (p. 41)

While not assessed at Rutherglen, there is also the potential that shelterbelts could enhance crop production on sandier soils through the provision of protection from physical damage caused by sandblasting.

Pasture production

According to Radcliffe (1983) the effect of shelter on:

... micro-climates, soil erosion, horticultural and agricultural crop production, windborne diseases, and livestock production is well documented, but there is little information about the response of grasslands to shelter ... (p. 5)

Radcliffe suggests that the mechanisms by which plant growth are improved are through the amelioration of micro-climate (primarily reduced windspeeds and warmer temperatures) and by more efficient plant use of water. However, as noted by Radcliffe (1983) very few studies have actually examined wind or shelter effects on pasture quality. Nevertheless, it is widely assumed in Australia that more pasture is grown and consumed by sheep in shelter than in exposed paddocks.

Until recently, only the study of Lynch and Donnolly (1980) has examined, although somewhat indirectly, the response of grazed pasture to shelter. This study is discussed in more detail in the following section Another more recent study conducted by the Johnstone Centre of Charles Sturt University and the University of New England (Walpole, in press) which indicates that the:

... gross values of pasture output is at its highest level when the proportion of tree cover is at 34%. That is to say, the productivity from pasture and grazing stock increase until about one-third of the farm is covered by woodland (a similar situation has been described for many crops). (p. 48)

Livestock production

Bird (1993) suggests that there are primarily two mechanisms by which shelter can improve livestock production and survival. The first involves increasing the supply of pasture, while the second involves reducing environmental stress on animals. As the role of shade and

shelter in increasing pasture supply has already been dealt with in the preceding section, the focus of this section will be on the role of shade and shelter in alleviating environmental stress.

Heat stress is the main climatic problem which affects the productivity of stock in tropical Australia, and although less of a problem, it can also affect stock in temperate Australia (Fitzpatrick 1994). Reid and Bird (1990) confirmed what more thoughtful farmers have suspected — heat stress can markedly reduce stock fertility, milk production, and weight gain, and increase mortality of calves and lambs. (p. 320)

Further to this, Fitzpatrick (1994) states that:

The use by cows of available shade has been correlated with improved calf growth rate to weaning. (p. 11)

For instance, he argues that cows resting in the shade chew their cud whereas cows in the sun refrain because rumination can also increase heat production. As chewing cud is important for livestock production, the cow with access to shade has greater opportunity for weight gain.

With regard to sheep:

... sheep can suffer from heat stress and production is reduced by lowering ewe and ram fertility, reducing birth weights, increasing lamb mortality and reducing feed intake, particularly in subtropical areas. (Fitzpatrick (1994); p. 12)

Newly born calves and lambs, are particularly susceptible to cold stress (Reid and Bird 1990). As alluded to earlier, the problem with cold stress is that animals are required to divert energy from production towards activities that involve keeping warm. An example of the economic consequences of this energy diversion has been provided by Fitzpatrick (1994), who recalls:

...shelterbelts that protected a farm from the prevailing wind were cut down to provide extensions to an airport runway near Auckland, New Zealand. In the following season, in spite of a district increase of 5% in milk production, the farm's production fell by 11%. (p. 12; citations omitted)

But it is not just cattle that are affected by cold stress, as sheep, and new born lambs in particular, are also vulnerable.

Studies in south-eastern Australia show that lamb mortalities are decreased when adequate shelter is provided. (p. 13; citations omitted)

For instance, Reid and Bird (1990) present the results from two separate trials in south-western Victoria whereby:

... shelter from the wind reduced lamb mortality by over 10% for single lambs. In one of these trials during a 5-day period of windy, cold, wet weather the mortality was 40% in the exposed flock but only 12% in the sheltered flock. The windspeed in the area sheltered by trees was 8 km/h compared with 22 km/h at the exposed site. The mean temperature was 7.4°C and 57 mm of rain fell during the period. (p. 322)

Lynch and Donnelly (1980) conducted one of the first studies in Australia on the effect of shelter on the growth and productivity of animals and pastures. These authors found that:

...sheep were being studied to see if their socialising instincts affected their production. To this end they were kept in small paddocks. Some of the sheep were kept out of the sight of sheep by galvanised iron barriers 1 m high. Others were enclosed by wire fences. The plots

sheltered by barriers had 18% more pasture and when the paddocks were stocked at 37.5/ha, so that the sheep used the extra pasture grown within the shelter, the sheep produced an average of 35% more wool and 21% more liveweight than unsheltered sheep. It was postulated that the improved production in the sheep behind the iron barriers was due to a reduction in windspeed which reduced evapotranspiration of the plants (evaporation from plant surfaces) and reduced the energy lost by exposure in the sheep. (Fitzpatrick 1994; p. 14)

Models of impact on production

Current work conducted under the umbrella of the National Windbreak Program (coordinated by the Joint Venture Agroforestry Program) is investigating the use of models to predict the effects of windbreaks on crop and pasture growth.

There is a need for integrating models of tree growth, crop and pasture growth, animal production, biodiversity, water/nutrient movement etc to provide advice at the catchment scale on ways to best design systems for improved farming, forestry and biodiversity benefits. As a first step, a project funded by the Joint Venture Agroforestry Program is using the TOPOG model to simulate the effects of different agroforestry designs on catchment hydrology and tree growth under a range of environmental conditions.

3.3.2 Pest control

Washusen and Reid (1996) claim that if adequate populations of native animals are maintained after a change of land use from native forest to farming, then biological control of insect and animal populations can occur.

The role of fauna

Washusen and Reid (1996) assert that all birds require insects as a source of protein for their young. This view was supported by Ford (1991), who indicates that virtually all bird species feed on insects to a greater or lesser degree and, in so doing, can contribute to suppressing herbivorous insect populations.

Ford (1991) provides an account of some more common predator–prey relationships observed between birds and insects:

Christmas beetles are eaten by cuckoo-shrikes, kingfishers and the larger honeyeaters, while whistlers snatch leaf beetles and caterpillar from eucalypt foliage. Cuckoos too eat larvae, specialising on unpleasant and hairy species. The smaller honeyeaters eat many insects, especially in spring and summer, particularly concentrating on the sap-sucking lerp and scale insects. The tiny pardalotes, thornbills and wrens also eat a wide range of insects. Flycatchers and swallows take beetles and moths as well as flies. Even parrots include insects in their diet. (p. 3)

However, most of the above relationships are specific to insects that inhabit trees and shrubs, and hence their impact on the more common agricultural pests is questionable. But Ford (1991) also claims that birds eat pasture pests as well. For instance:

Magpies are most important in this respect, taking thousands of scarab larvae per hectare each year. Ibis may consume large numbers of insects from pasture, particularly grasshoppers and larvae but their activities are often local. (p. 3)

A view also held by Washusen and Reid (1996):

Large flocks of Ibis commonly consume hundreds and thousands of crickets, caterpillars and grubs from our pastures each day. (p. 65)

But according to Ford (1991) it should be realised that predation of pasture insects by birds is likely to be greatest where pasture and woodland meet. This is because:

Magpies feed on the ground but require trees for nesting. Many woodland birds like choughs and some of the flycatchers, robins and wrens may venture into pastures to forage. Birds may also take pasture insects like scarab larvae and grass grubs as adult insects when they are in flight or feeding or resting on trees. (p. 4–5)

Based on these assertions, Cadman et al. (1991) believe that the revegetation of cleared agricultural land is likely to result in a large increase in the diversity of bird life. They report that studies at the University of New England in Armidale have shown that increases in the bird population can halve the level of insects on a rural property (Cadman et al. 1991) from somewhere in the vicinity of 60 kilograms per hectare to 30 kilograms per hectare (Russell et al. 1991).

Yet Ford (1991) makes the point that the effectiveness of revegetation to encourage the return of birds will vary depending on the configuration of the tree plantings. For example, he states that large block of trees are better for birds than individual trees scattered throughout a paddock. In support of this notion, he recounts a study of birds in woodlands on the Northern Tablelands of New South Wales whereby:

...woods of 1 hectare (ha) held about six species of bird whereas 5 ha woods had nearly 20 species. Most birds require a minimum size of habitat for their breeding territory, this is often in the range of 1-3 ha. Thus blocks of woodland of 3 ha or more spread throughout pasture would hold a reasonable abundance and diversity of birds. (p. 5)

However, Ford (1991) also states that while large blocks of trees are obviously better, structural variation and a wide range of plant species can also increase the diversity of birds and other wildlife. But what about the role of other wildlife? Washusen and Reid (1996) note that small insectivorous mammals such as the Squirrel Glider and Sugar Glider have been recorded as eating up to 300 grams of Christmas beetles in one night. Further to this, Ford (1991) states that small mammals like sugar gliders and predatory insects and spiders can take a significant proportion of those insects which are not consumed by birds.

In summary, Ford (1991) concludes that the average level of attack by insects and the frequency of outbreaks would be considerably higher without the above-mentioned natural predators. Yet, according to Ford (1991), little provision is made on farmland to provide habitat for these protectors. He believes that farmers should manage trees to encourage insectivorous birds in just the same way that they manage their pastures.

The role of flora

Halvorsen (1998) reports that Queensland sugar cane farmers are planting trees along river banks to control damaging rat populations. The rationale behind this approach is that:

Rats prefer to live in grassy, weedy areas, such as those found along creeks and river banks near cane fields. Planting a mix of 15 native species ... in these areas creates a closed canopy that shades out the weeds and grasses rats need for survival. (p. 6)

Halvorsen (1998) claims that in the wet tropics:

quick growing trees develop full canopy closure within a few years, killing vegetation in the understorey and taking away rat habitat. (p. 6)

She indicates that rat numbers can be reduced by 80–100 per cent in two years.

3.4 New products for sustainable production

3.4.1 Wood

Five different groups of wood products are recognised by Abel et al. (1997). These are:

- sawn timber products;
- composite boards;
- paper and cardboard;
- posts and poles; and
- fuel wood.

However, it is beyond the scope of this review to discuss these groups here, therefore readers requiring more information are referred to Abel et al. (1997), Reid (1995), Fitzpatrick (1994) and Race (1993). Instead, the focus of this section of the review will be on those factors which are most likely to impinge on the viability of a farm forestry (wood products) venture. These are considered to be: site selection; species selection; silviculture and harvesting; and product marketing and sale.

Site selection

Abel et al. (1997) point out that like all crops:

Site quality greatly influences tree growth and productivity. For trees we generally consider soil depth, texture and the degree of exposure as the most important criteria. (p. 14)

The same sentiment is also stressed by Loane (1993) who asserts:

Rainfall and site will determine feasible species and growth rate and whether the trees can attain marketable size in reasonable time. (p. 73)

Turvey (1990) suggests that the potential productivity of a site reflects:

...the net effect of the amounts of solar radiation, temperature, carbon dioxide, rainfall and nutrients that the site receives. (p. 5)

According to Turvey (1990) the maximum productivity of the site can be manipulated by modifying the soil in which the trees grow, the position of the site in the landscape, and the addition of water through irrigation.

Species selection

Reid (1995) provides some pertinent advice on species selection:

Existing markets in each region reflect the available resources whether derived from native forests or from plantations. If you are considering supplying large local timber processors, do your homework first and find out what species the industry in your area are likely to process and want to market. Throughout Australia, the larger softwood timber mill, and many of the native hardwood mills, are specialising in one, or a select few, species which are available in large quantities from either native forests or plantations. (p. 12)

Booth and Jovanovic (1991) predicted the area of land capable of supporting hardwood plantations based on the critical parameters of climate, soil and topography.

Commercial viability

Boutland (1991) has observed that most economic studies of agroforestry in Australia are based on 'best bet' estimates and/or computer simulations rather than actual price. It has been suggested that this is because agroforestry is relatively new in Australia, and there are not many agroforests that have reached the end of their rotation.

Gisz and Sar (1980) conducted an analysis of the costs and returns for a 25 year radiata pine plantation in the Tarago region of the southern Tablelands of New South Wales. Gisz (1982) revised this study to reflect actual costs incurred, and to increase the mean annual increment. The results of the revised study indicated that investment in agroforestry in the Tarago region is more viable than sheep grazing alone, where the interest rate is less than 12.75 per cent (Boutland 1991).

Dunchue and Sinclair (1994) recommended that in areas of the Eastern Murray Catchment that experience greater than 750 mm annual rainfall, wide space and/or close spaced *P. radiata* and *A. melanoxylon* are suitable for the production of sawlogs. In areas that receive between 600-700 mm annual rainfall, *E. maculata* is recommended for the production of posts, poles and sawlogs.

The stumpage rate of both *P. radiata* and eucalypt pulplogs is approximately \$12 per cubic metre (Treecorp Pty Ltd 1993). However, for a mechanical harvesting operation to be viable, a resource of about 1,000 cubic metres in an area is needed. This equates to the clear felling of approximately 5 hectares of 15 year old plantation.

Dunchue and Sinclair (1994) have indicated that as a result of the current oversupply of *P. radiata* pulplogs, dense plantations are not recommended for farm forestry.

The ash and blue gum eucalypts are favoured for the production of high quality paper and tissues due to the short fibre length and strength (Treecorp Pty Ltd 1993). Kellas and Yule (1991) have reported that eucalypt pulpwood for export from Bunbury and Manjimup in Western Australia could return a net present value of between \$902 and \$3277 per hectare for a ten year rotation located within 100 kilometres of processing facilities. In Western Australia, southern blue gum (*E. globulus*) is the principal species recommended.

Process based tree growth models

There is a variety of models of varying complexity that can be used to predict growth and water use of plantations. Some of the more common models are as follows.

- PLANTGRO is used to formalise the environmental relationships of lesser-known plants (Marcar 1998). The PLANTGRO model has been used by Booth (1996) to describe the environmental relationship of trees and also to provide tentative indications of their potential performance over vast areas.
- BIOMASS is a daily time-step model which predicts photosynthesis by the canopy of a whole stand of trees in relation to water availability and crown nutrient status.

Marcar (1998) considers the model robust in its ability to model the water balance, but deficient in its ability to model respiration and various growth components.

- The G'DAY (Generic Decomposition and Yield) model has been developed to examine the effect of climate change on forest productivity, by dealing with the components of nitrogen cycling and organic matter decomposition (Marcar 1998).
- CenW (Carbon, energy, Nutrients and Water) is a generic model that simulates the growth, water use and nitrogen cycle of uniform stands of trees on a daily time-step. Marcar (1998) suggests that this model can be used to examine the effect of environmental or silvicultural factors on tree performance.
- WATLOAD is an empirical water-balance model that calculates the maximum water use rate for plantations from the development phase, before complete occupation of a site, through to full maturity. (Marcar (1998) p. 305)
- The TOPOG_IRM model is based on a plant physiological module which is used to predict growth and water use (Marcar 1998). The model is primarily used to determine the most appropriate landscape positions for maximum water use by trees.
- The ProMod model predicts the growth of a forest following canopy closure. Its principal output is a peak mean annual increment, and it can also estimate closed-canopy leaf area index, evapotranspiration and water use efficiency. In addition, an indication of biomass partitioning around the time of peak MAI and the relative effects of different environment factors in limiting production can be obtained. ProMod can be used by forest managers to screen prospective plantations sites and can also predict the seasonal variation in production (Battaglia and Sands 1997).
- The 3-PG (Physiological Principles in Producing Growth) model is a forest stand growth model. It calculates total carbon fixed from utilisable, absorbed photosynthetically active radiation, obtained by correcting the photosynthetically active radiation absorbed by the forest canopy for the effects of soil drought, atmospheric vapour pressure deficits and stand age (Landsberg and Waring 1997).

3.4.2 Other products

According to Fitzpatrick (1994), non-wood forest products significant in Australia include: essential oils, honey and pollen production, wildflowers and tree foliage, broombrush, sandalwood, seed, Christmas trees, drugs, tannins, gums, resins, cane and charcoal.

Curtis and Race (1998) investigated the potential of a carob industry in the Murray-Darling Basin. Carob, the fruit of the tree species (*Ceratonia siliqua*), is used in confectionary, pet food and as a non-animal substitute for gelatine. They concluded that at the higher value end of the market, a viable niche exists for a small carob industry in the region.

The Murray Darling Basin Commission funded the Australian Bureau of Agricultural and Resource Economics to conduct an analysis of the production and market trends of jojoba, blue mallee, and broombrush (McKelvie et al. 1994). It is thought that these perennial shrubs may have potential for controlling recharge in the cereal growing areas of New South Wales and Victoria. The findings of this study, as well as other relevant studies, are summarised as follows:

- Domestic demand for jojoba is low compared with expected production increases, and without product promotion and education is likely to remain low (McKelvie et al. 1994).

The overall success of the domestic jojoba industry would appear to lie in its ability to compete with imports, and create market demand.

- A market for brush fences is already well established in the major capital cities of Australia (McKelvie et al. 1994). Stricter controls on the harvesting of native stands on both private and crown land may result in shortage of supply. Bulman et al. (1991) has assessed the profitability of growing broombrush using three different establishment techniques (direct seeding, non-irrigated seedlings, irrigated seedlings). The results suggest that broombrush would only return \$8.50 per hectare per year by direct seeding, while non-irrigated seedlings would not be profitable, and irrigated seedlings only under optimistic circumstances.
- Eucalyptus oils on the international markets are currently in oversupply (McKelvie et al. 1994). The current domestic eucalyptus oil industry consists of two major distillers and exporters, located at West Wyalong in New South Wales and Inglewood in Victoria. The survival of the domestic eucalyptus oil industry can be accounted for by the supply of high quality oil to a niche in the world market, and the mechanical harvesting of blue mallee (*E. polybractea*) which has not been successfully grown overseas. Abbott (1986) has suggested that there could be potential for small scale production of eucalyptus oil, as a resource of approximately 200 hectares could support a small still which could be set up for a few thousand dollars.

3.5 Off-site production effects

3.5.1 Carbon sequestration

Cadman et al. (1991) have claimed that deforestation currently contributes between 25-35 per cent of worldwide carbon emissions. Tree planting on a large scale could help slow the enhanced greenhouse effect. This would not be a permanent solution – since wood eventually decomposes or is burnt (Barson and Gifford 1990a) – unless the biomass of plantations is used to replace fossil fuels as an energy source.

The process by which trees and other plants can potentially ameliorate the greenhouse effect is described by AACM et al. (1997):

One way to remove carbon dioxide from the atmosphere is to grow more vegetation. This is referred to as carbon sequestration. There are two reactions that go on daily in a leaf: photosynthesis and respiration. Photosynthesis converts atmospheric carbon dioxide into carbon and oxygen with the addition of energy (sunlight). Respiration combines carbon and oxygen to create carbon dioxide and energy. The two do not balance, and the net carbon is stored in the form of biomass (leaves, branches, stems, and roots). (p. 6)

Increasing the amount of vegetation is not a complete solution to the global climate change problem, but it may provide the buffering capacity needed to develop responses that deal fundamentally with release to the atmosphere of fossil carbon (AACM et al. 1997).

Measuring carbon sequestration

According to Barson and Gifford (1990b):

The establishment of new areas of young, vigorously growing trees on already cleared land provides a transient opportunity to lay down new organic matter faster than it is re-oxidised. About half of the mass of organic matter that constitutes the stems, leaves and roots of plants is carbon. Hence as a forest grows on land previously under crops or pastures, carbon is stored, mostly as wood. Forests are able to store more carbon than do annual crops and

pastures, since trees build up a much bigger store of organic matter before dying and decomposing. However, forests eventually reach a stage of maturity when the rate of decay back to CO₂ matches the rate of net carbon fixation, at which point there is no net carbon sequestration per unit land area. (p. 434)

In order to test some of these assumptions, Barson and Gifford (1990a) have developed a carbon sequestration model based on 40 000 hectares of *Pinus* or *Eucalyptus* being planted each year of a 40 year rotation. From this model they estimated that these trees would sequester an average of 7.5 tonnes of carbon annually for each hectare planted. Australia emits 4 tonnes of carbon per person each year (Barson and Gifford 1990a). Therefore based on these estimates, each person in Australia needs around 0.5 hectares of trees to balance their annual carbon budget.

More recently, AACM et al. (1997) have developed a simple accounting model for tracking carbon sequestration in forest-related projects. The model has eight pools with differing degrees of permanency. The structure of their model provides some useful insight into the potential role of trees and shrubs in carbon sequestration. For instance, they recognise that *trees and roots*, *soil*, *other vegetation* and *fossil fuel* are the longest lived pools, with *litter* and *long-lived wood products* of shorter duration, and that short-lived pools such as *short-lived wood products* and *biofuels* emit carbon to the atmosphere soon after creation.

With regard to the *trees and roots* pool, AACM et al. (1997) advise that:

This pool changes through net (photosynthesis minus respiration) sequestration from the atmosphere (growth), direct emission to the atmosphere (fire), creation of forest floor litter (leaves, twigs, other deadfall and harvest waste), and harvesting. Depending on forest type this pool can account for between 50-75% of stored carbon. (p. 8)

However, it should be noted that growing forests or stands increase the carbon pool with time, while mature stands are at a steady-state where additions to the pool through carbon sequestration are equivalent to losses from the pool resulting from tree death and litter generation (AACM et al. 1997).

In assessing the effectiveness of vegetation for carbon sequestration, it is important to note that AACM et al. (1997) have distinguished two different types of wood products. One type that includes building materials, furniture and fencing is long-lived, and the other, which includes paper products, is short-lived. Therefore, it can be assumed that trees that are planted for nature conservation are more likely to lock up carbon for a greater period of time than, say, trees that are planted for pulpwood production.

According to AACM et al. (1997) the amount of carbon stored in the *trees and roots* pool can be estimated by three different techniques.

- (1) The first techniques for estimating above ground biomass is to use existing data, such as standard forestry tables that estimate commercial timber volume. Such tables are developed routinely to enable estimation of volume of commercial timber yield but would have to be converted to the carbon weight represented by the yield volume.
- (2) Another approach is development and/or use of allometric equations for the tree species represented in the forest. In some instances these equations will have already been developed by research foresters. Allometric equations relate tree diameter at breast height (dbh) and tree height to the amount of above-ground biomass stored.
- (3) A third approach is to use remote sensing to directly estimate the carbon stored. This approach is far less accurate and probably not feasible for a small project. (p. 22)

Carbon credit schemes have been raised as a potential means of generating funds for rural tree planting schemes (AACM 1997). Under such schemes, companies that emit CO₂ and other greenhouse gases to the atmosphere can 'offset' these emissions by funding efforts to sequester carbon. According to Gottlieb (1998), a number of companies (including BP, Shell, Du Pont and Toyota) are already investing in pilot carbon credit schemes in the expectation that a carbon credits trading system will become established in the future. Such a system could assist in funding land rehabilitation more broadly than just tree planting: Francis (1998), for example, suggests that farm activities such as forestry, landcare revegetation, pasture improvement (particularly using perennial species such as lucerne, tagasaste, saltbush and leucaena) and soil structure improvement that sequester carbon could be used in carbon credits schemes.

The impact of climate change on production

With regard to climate change and agriculture the impact on agricultural production in Australia, according to Campbell et al. (1996):

Areas of consensus are beginning to emerge with respect to pasture and rangeland responses to CO₂ and climate change. Predictable positive and negative effects on pasture and livestock production are expected, and there are likely to be regional differences in the effects. It is expected that CO₂ will increase yield, but the exact amount of this increase is unclear. (p. 185)

In the forest sector, Landsberg (1996) argues that:

The impacts, if any, of climate change on planted forests will be apparent either as progressive change in the suitability or otherwise of particular areas for forestry, or through changes in the growth and yield of forests as a result of changing conditions. (p. 205)

3.5.2 Infrastructure

There is virtually no literature to support the notion that tree planting can be linked with reduced infrastructure damage. Nevertheless, there is speculation that if trees can control dryland salinity and rising watertables then they will also contribute indirectly to a reduction in infrastructure damage. Tree-planting already forms part of some strategies to reduce infrastructure damage: for example, tree-planting in Merredin (Western Australia) is aimed directly at lowering the watertable under the town (Saunders personal communication).

Private infrastructure

A saline environment promotes the deterioration of both urban and rural infrastructure: from houses, roads and drains to farm improvements such as sheds, fences, and roads (MDBC 1993). Booth (personal communication) suggests that an integrated approach to urban salinity is needed. This could include: tree planting; reducing urban irrigation (garden water); replacing rumble drains (which drain directly into gardens) with stormwater drain connections; and pumping out groundwater.

Plants may be used to slow or divert fire in order to protect property. According to Chapman (1990) shelterbelts established to protect buildings from fire (by slowing windspeed and deflecting sparks) should be orientated at right angles to the prevailing fire direction and extend at least 100 m beyond any building to reduce the likelihood of increased turbulence.

Public infrastructure

Rising watertables may result in saturation damage to roads, but it is uncertain as to how much the actual salinity is implicated in this damage (Hook 1992). Other public utilities that may be damaged as a result of dryland salinisation include bridges, culverts, fences (Hook 1992), pipelines, underground communication cables and the footings of electrical transmission towers (MDBC 1993).

3.6 Implications for indicators

3.6.1 Conservation outcomes and production

Despite the widespread use of contour banks and grassed waterways, and relatively limited revegetation, there are no quick-fix solutions to many soil degradation problems. People need to be aware that solutions may be complex, should be ecologically based and take decades to be effective.

Trees, shrubs and grasses that are effective at controlling erosion are likely to have a positive benefit on production. This is because effective erosion control can not only reduce the amount of land taken out of production, but may also reduce declining production on remaining land, through conservation of ecosystem resources such as soil and nutrients. It is possible that increases in production can be achieved through the soil enhancing characteristics of some trees and shrubs.

3.6.2 Shade and shelter and production

Trees have a role in the provision of shelter to plants and animals. In dryland cropping areas, reduction in evaporation appears to be the most important factor. Moisture that is conserved in the sheltered zone can be used by plants later in the growing season, particularly during the critical times of flowering and grain filling. There is also the potential that shelterbelts could enhance crop production on sandier soils through the provision of protection from physical damage caused by sandblasting. Shelter may improve plant growth through the amelioration of micro-climate (primarily reduced windspeeds and warmer temperatures) and by more efficient plant use of water. Trees planted for soil conservation purposes may also be effective in ameliorating adverse microclimate.

Shade and shelter have beneficial effects on stock by reducing environmental stress from heat and cold. Shelter provided by windbreaks reduces wind speed and reduces the energy lost by exposure in stock. Indications are that productivity from pasture and grazing stock increase with the provision of cover until about one-third of the farm is covered by woodland. A similar situation has been described for many crops.

All domestic plants and animals require shade and shelter, but the degree to which an economic return will result from the provision of this protection will depend on the climate and topography, the species and age of plant or animal. The value of shade and shelter in terms of gains in production do provide an economic incentive to land holders to improve the climate on their properties.

3.6.3 Pest control and production

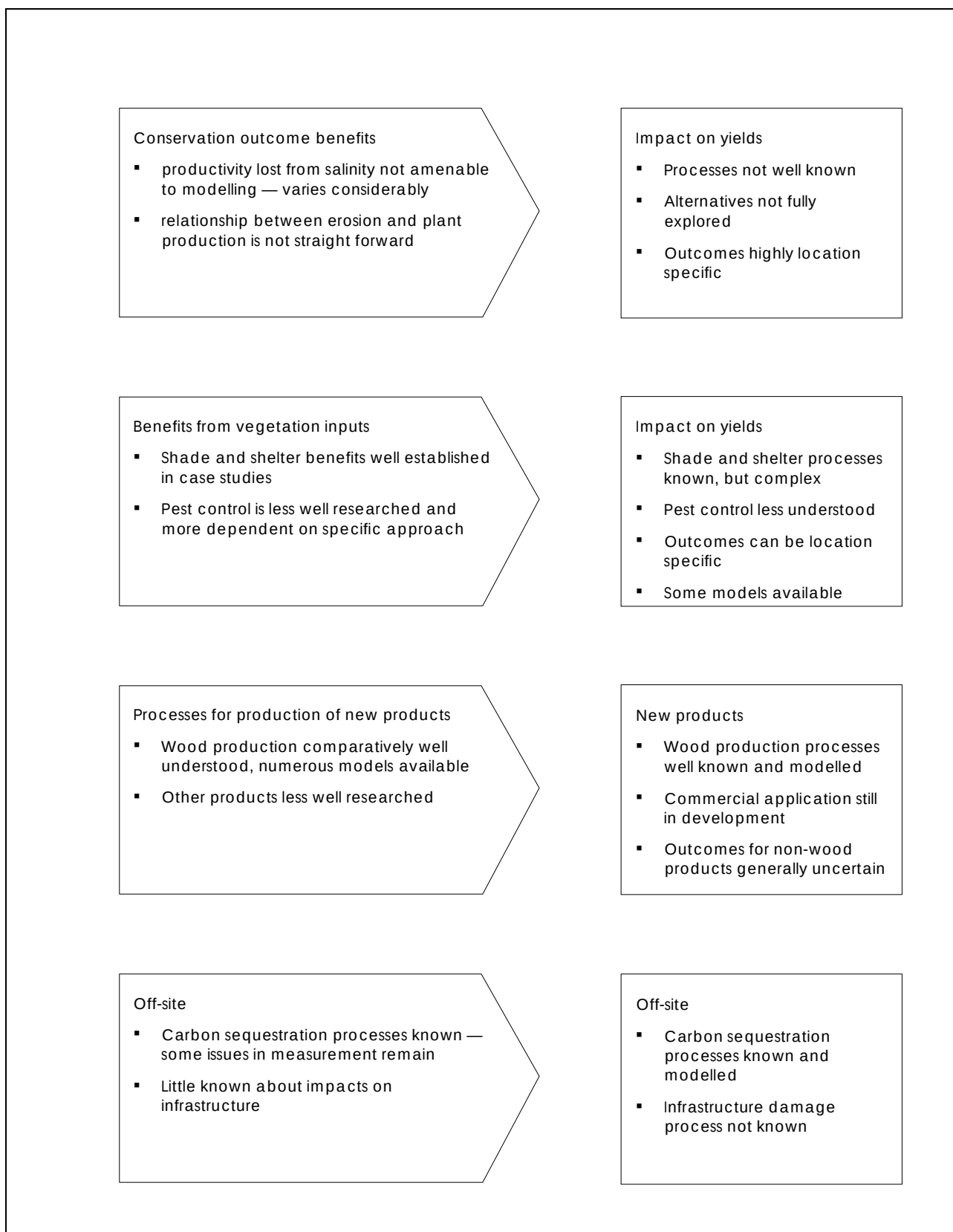
Remnant native vegetation and revegetation provide habitat for birds and insect that prey on insects that are agricultural pests. Without these native predators, the average level of attack on agriculture by insects and the frequency of outbreaks may be considerably higher. At present little provision is made on farmland to provide habitat for these predators. It may be economically beneficial for farmers to maintain their remnant vegetation and to revegetate to encourage insectivorous birds and predatory invertebrates in the same way that they manage their pastures. The linkage between vegetation and the reduction in agricultural pests will be dependent on the effectiveness of the vegetation as habitat for predators of the pests. Creation of additional habitat through revegetation is more likely to attract predators of agricultural pests when located next to existing remnants. Habitat suitability is another important factor: species of plant from the area (local provenance) may be more likely to support predators of agricultural pests than exotic species.

3.6.4 New products

Trees planted for wood production generally require an existing market in order to be economically viable. Species need to be carefully selected on the basis of site capability and marketability. Many of the existing commercial species are well suited to farm forestry as they pose less of a problem to farmers who usually have trouble in guaranteeing continuity of supply. Careful and timely silvicultural management is crucial to the production of high quality wood products.

Non-wood forest products significant in Australia include: essential oils, honey and pollen production, wildflowers and tree foliage, broombrush, sandalwood, seed, Christmas trees, drugs, tannins, gums, resins, cane and charcoal.

Chart 3.2 **Summary of findings**



3.6.5 Carbon sequestration

Increasing the amount of vegetation is not a complete solution to the problems posed by global climate change. However, it may provide the buffering capacity needed to develop responses that deal fundamentally with release to the atmosphere of fossil carbon. Any attempt to measure the effectiveness of trees in sequestering CO₂ will need to take into account the growth rate of the vegetation and the purpose of the tree planting.

3.6.6 Other uses

Trees can assist in protecting property against the threat of fire. Tree planting may also constitute an important part of an integrated response to urban salinity problems.

There is a need for integrating models of tree growth, crop and pasture growth, animal production, biodiversity, water/nutrient movement, etc to provide advice at the catchment scale on ways to design the most effective systems for improved farming, forestry and biodiversity benefits.

4 Investigating the socioeconomic impacts

The previous two chapters have examined the biophysical processes by which changes in vegetation management and revegetation can impact on the natural environmental and sustainable production. However, understanding the biophysical processes is only the first step in evaluating the potential success or otherwise of the Bushcare and Farm Forestry programs. For the programs to have a large pay-off to the community they must change behaviour — it is only with widespread action that the full benefits can be obtained. This is because of the need for a critical mass of vegetation, and because of externalities.

- As discussed in chapter 2, a large critical mass of revegetation is often required to combat degradation problems such as dryland salinity and erosion. This is less of an issue for soil structure decline and acidity problems where the effects of degradation tend to be more localised.
- For farm forestry critical mass is also an issue. High fixed costs of establishing processing facilities and high transport costs require relatively large minimum volumes at a regional level for farm forestry to provide a good return to the farmers from wood sales.
- There are substantial externalities in the benefits of revegetation. As the benefits of a revegetation activity do not fully accrue to the landowner the market will deliver a sub-optimal amount. Cooperative behaviour will raise the overall benefits for all.

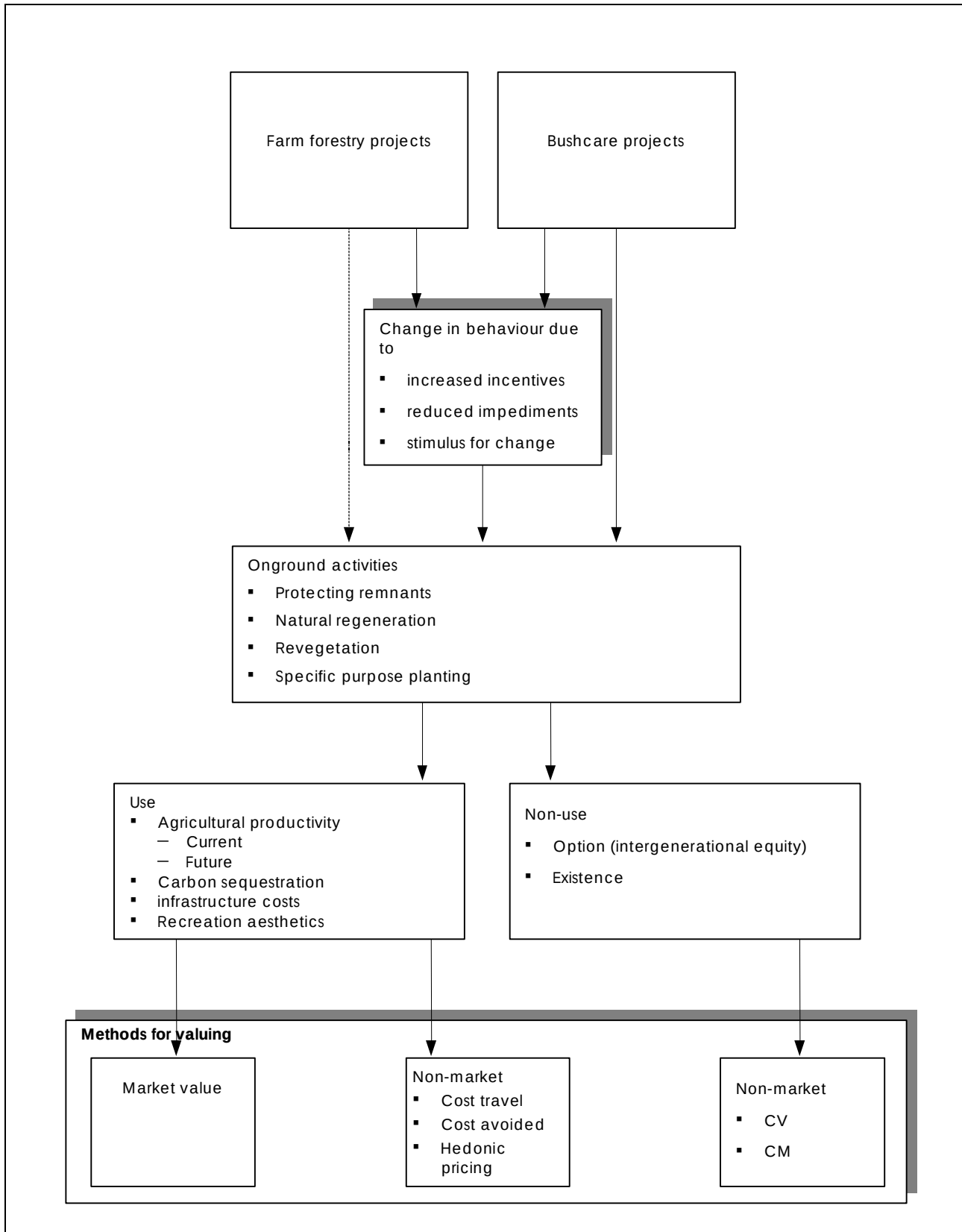
The FFP focuses largely on changing farmer behaviour. The projects develop and provide information both on the pay-off and the ‘how-to’ — providing training, identifying barriers, improving systems and lowering costs for farmers planting trees. Bushcare also uses these avenues but the main approach in this program to influencing attitudes is through education and example. The links in chart 1.2 between the intermediate outcomes of changes in people and institutions and actions are explored in the first part of this chapter.

Chart 4.1 draws out these links and also the links between the final outcomes and the value placed on those outcomes. The final outcomes — reduced salinity, reduced soil degradation, improved biodiversity, carbon sequestration, improved agricultural yields, and wood and non-wood products — have both use and non-use values.

Use value may be for uses that are within the market system, making estimate of values reasonably easy. However, they can be outside the market system requiring different techniques to estimate value. Non-use values are outside the market system, and estimates of value have to be extracted from survey questions that reveal willingness to pay. The second part of this chapter summarises the various methodologies for putting values on environmental and sustainable production outcomes.

4.1 People and institutional outcomes — do they lead to change?

Chart 4.1 **Measuring changes in behaviour and values of final incomes**



In both the FFP and the Bushcare program a key aim is to change the behaviour of landowners and community groups to undertake actions such as tree and shrub planting, earthworks, fencing and other actions to support revegetation. Self-sustaining activities can be generated by projects that:

- raise awareness of the benefits of actions — to the landowner in improved yields, alternative products, improved land values (long term yields), and to the community in lower infrastructure repair costs, reduced inputs into water quality control, amenities such as recreation, and for inter-generational equity;
- improve the skills to facilitate actions — management skills including selection of site and species, silvicultural practice, planting and maintenance regimes;
- reduce the cost of actions (improving efficiency) — through better management systems, improved inputs, more effective design, and improving survival rates for example; and
- raise the value of the actions performed — for example, improving coordination between landowners (cost effectiveness), or ensuring appropriate location decisions.

Where FFP or Bushcare projects raise the return on actions for the individual, economic models can be used to find the required return to give an incentive to change behaviour. But this does not guarantee a change in behaviour. Providing incentives and removing the impediments to action — knowledge, skills, cost and return — is not always enough to ensure change.

- Uncertainty creates barriers, as decision-makers cannot know with certainty the net benefits of the various alternatives. Chapter 2 demonstrates the considerable degree of uncertainty about the processes by which revegetation and protecting remnant vegetation will deliver environmental benefits. And in chapter 3, while the processes for wood production are well known, and the benefits from shade and shelter are reasonably well established, there is still uncertainty at the local level about the transferability of the results.
- There is an aggregation problem, as general net benefits are not always applicable in all cases, and many may think they are exceptions. While this is associated with uncertainty, it goes beyond this. It is the excuse arising from inertia, which is a resistance to change as it takes effort to change.
- There is an idiosyncratic risk problem, as individual risk of failure of actions to deliver benefits is greater than the collective risk, so the individual optimum is not the collective optimum.
- There is a temporal problem, as individual's discount rates, the rate at which they are willing to trade off things in the future for things now, vary. Individual discount rates are generally higher than community rates.

The institutional and people outcomes in the Bushcare and Farm Forestry programs aim at reducing the individual risk of failure, and addressing inertia by encouraging networks and cooperative approaches. Research programs are largely about reducing the uncertainties and improving transferability. However, it is only direct assistance that can overcome the problems introduced by different discount rates, unless education and exposure to new ideas changes people's time preference.

Economic modelling can be used to understand how agents would react to changes in incentives. But it faces two problems:

- where public benefits are not optimised by actions that maximise private benefits, additional incentives are required to produce optimal outcomes; and
- evidence from sociological studies suggests that people are often willing to undertake activities for non-pecuniary reasons — the only benefits being satisfaction and perhaps self-esteem. So it would be wrong to dismiss this avenue of transmission for benefits.

In practice, economic models often perform poorly in predicting changes in behaviour for the reasons (problems) outlined above. Thus, we tend to rely on direct evidence of changes rather than any inferred change from changes in measured incentives. But estimating the changes in incentives is still a good place to start — without this there is no reason to change behaviour.

4.1.1 Is pecuniary return the main incentive for adoption?

The pecuniary incentive to undertake farm forestry or Bushcare is measured by the required rate of return. This is the return these activities must deliver for them to be undertaken — the return on alternative uses of the funds, labor, land and materials. The expected pecuniary returns are discussed in the second part of this chapter.

For many activities the pecuniary return forms only one part of the motivation for changing behaviour. This becomes clear when the reasons why farmers plant trees is examined. The *1994 Survey of Trees on Farms* (Wilson et al. 1995) found, Australia-wide, 81 per cent of tree plantings in the 1991–94 period were for shade and shelter and three per cent for wood (sawlogs or pulplogs). Fifty-eight per cent cited landcare and 29 per cent conservation purposes as the major motivating factor. While the overall findings are similar to those by Nicoll and Dobbie (1996) in the National Tree Survey, it is interesting to note how the emphasis changed with the different focus of the survey. The National Tree Survey focused more on landcare — and the responses indicated that a lower share of farmers (54 per cent) planted for shade or shelter, and a higher proportion for landcare reasons (50 per cent for dryland salinity control).

Just as interesting as reasons why farmers plant trees are reasons why they do not. Wilson et al. (1995) and Prinsley (1991) find that the loss of productive land is one reason. And Vanclay and Cary (1989) found that lack of perceived benefits was an important obstacle to changes in behaviour, despite a high awareness of the causes and solutions for dryland salinity.

It is an open question whether a pecuniary return is a necessary and/or sufficient incentive to adopt farm forestry. It raises questions about the timeframe over which a return is expected and about precautionary motives that are linked to expected returns.

The differences in survey responses also suggest that care should be taken in interpreting time series information from surveys, as they may reflect the current focus rather than actual reasons for establishing farm trees.

4.1.2 Survey evidence on changes in behaviour

There are several sources of survey evidence that are conducted on a regular basis allowing change in behaviour to be assessed. The main source of regular rural surveys is ABARE

(ABARE, 1992, 1993, 1994, 1995, 1996, 1997). However, most surveys on land degradation, revegetation, farm trees and related issues are not conducted annually.

- The 1997 Farm Survey included questions on Landcare membership, participation in training and adoption of the practice in normal farm operations. Membership by broadacre and dairy farmers in Landcare groups has increased from 24 660 in 1992–93 (27 per cent) to 29 274 (34 per cent) in 1996–97. Over half of all farmers had participated in at least one training course in the previous three years, and one third attended Landcare group workshops or field days. Clearly participation in training is correlated with undertaking land care activities, though no causation can be concluded. Overall, 48 per cent of all farmers had enhanced areas of conservation value (62 per cent in the group who had attended three or more activities), 33 per cent had monitored vegetation condition (47 per cent), and 56 per cent had maintained vegetative cover along drainage lines (68 per cent).
- From 1991–92 to 1993–94 ABARE conducted a supplementary survey of Landcare and land management practices. In 1992–93, 62 per cent of broadacre and dairy farmers reported a significant land degradation problem. Fifteen per cent of farms undertook tree and shrub establishment as a control mechanism. For farmers not undertaking any land care work, 50 per cent cited low cash availability as the main reason. Around 35 per cent of the farmers who had established trees and shrubs intended to claim under the landcare tax provisions, but slightly over 50 per cent did not, the remainder undecided.
- A supplementary survey in 1991 recorded participation in Landcare and tree planting activities (ABARE 1992). Forty-four per cent of farmers reported planting trees but only 25 per cent of these stated conservation as their main motivation. Twenty-three per cent of farmers reported belonging to a Landcare group. Participating farmers were found to be more likely to plant trees and adopt conservation practices.
- BAE, as part of their 1983–84 broadacre farm survey, questioned farmers on their perceptions of land degradation. At this time 44 per cent of farmers considered land degradation had occurred on their properties, and almost 40 per cent of farmers considered it to be a problem or potential problem. In the 1991–92 survey 67 per cent considered land degradation had occurred on their properties. While this perception level had increased, the proportion of farmers considering land degradation to be a problem or potential problem remained the same. This suggests, at minimum, greater awareness of the issues, and perhaps that actions had been taken or were planned to mitigate the problems.
- ABARE conducted a survey of trees on farms in 1994 (Wilson et al. 1995) the results of which are discussed above.
- ABS compile a number of statistics that might be useful inputs into estimating changes in attitudes to the environment (ABS 4601.0, 4602.0, 4603.0). The publication *Australian Agriculture and the Environment* (ABS 4606.0) summarises a variety of information collected by the ABS and other sources. While no specific questions about vegetation management are asked in the Agricultural Census, perceptions about land degradation are surveyed.
- The National Farm Forestry Inventory project, funded by DPIE, is developing a core data set to be completed by each farm forest grower that will record the area species, age and location of the resource. This is supplemented by a survey of 15 per cent of farm forest growers collecting additional data on site characteristics, tree growth and silvicultural practices.

- Queensland is conducting a statewide land cover and trees study over 1996–99. They are using this to develop accurate baseline vegetation data, and report on clearing activities and factors influencing clearing.

There have also been a number of ‘one off’ surveys that provide some evidence on how changes in attitudes affect behaviour.

- Dunn and Gray (1992) surveyed farmers in Young Shire, NSW on their views on dryland salinity. Questions about landcare group membership and level of concern were asked to gauge the farmer’s propensity for action and commitment. Thirteen per cent of the survey respondents belonged to a landcare group. Of these 24 per cent rated salting as more important than farm costs compared with 14 per cent in the full sample.
- Wilkson and Cary (1992) found an increasing awareness of landcare issues has resulted from Landcare and other community based movements. This awareness is correlated with an increase in tree planting activity over the last decade. But Cary et al. (1993) found no difference in tree planting effort between recent Landcare members and non-members.
- Nicoll and Dobbie (1996) found no relationship between the purposes for which trees were planted and the age of the first tree lot planted. But analysis of average plantings and areas demonstrated a dramatic increase in tree planting for land degradation control in the past 5 to 10 years.
- Vanclay and Glyde (1994) found in the central west of NSW that Landcare members plant significantly more trees than non-members. They relate this to increased awareness of degradation issues among Landcare members.
- Race and Curtis (1995) found that the 1300 hectares of demonstration plantings under the FFP had stimulated another 500 hectares of plantings during 1993–95.
- Reynolds (1997) undertook a survey of farmers in the Shepparton region for Victorian DNRE. Both views on future tree planting activities and estimates of activities over the previous five years were sought. Little interest was found, in the past for the future, in growing trees for wood production. The main reasons cited were good returns from current enterprise, and lack of knowledge. Financial incentives were found to be unlikely to change behaviour.

Only where attempts have been made in surveys to explicitly link the changes in attitude and behaviour to program actions can any casual relationship be interpreted. This makes it difficult to use raw statistics. For example, the higher share of people in farm forestry networks who plant trees for wood production compared with those not in networks could indicate that people who plant trees join networks rather than the networks lead to people planting trees. It is important that the survey explore the counterfactual — how many farmers would have planted trees (and how many) in the absence of the network.

4.1.3 Measuring multiplier effects

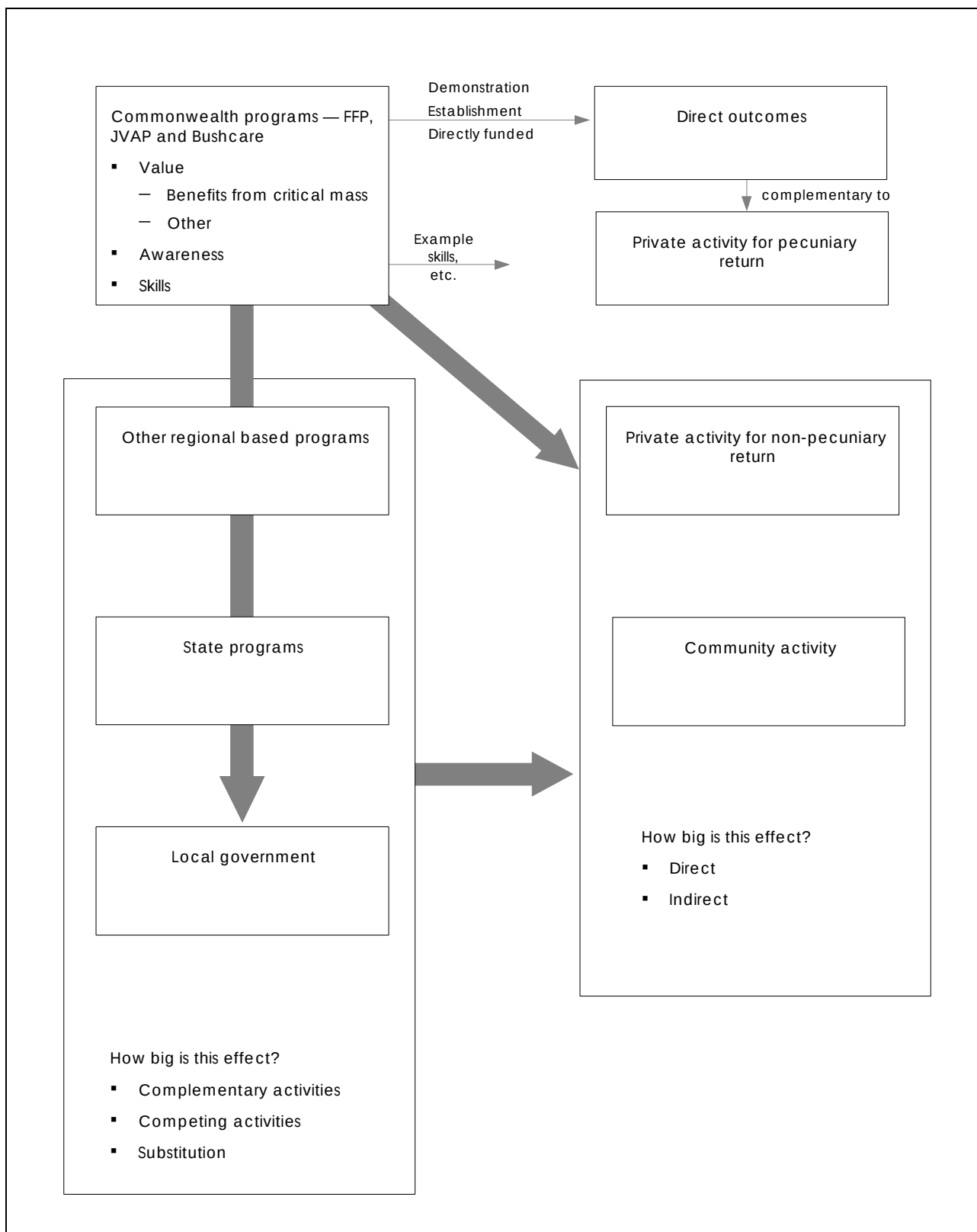
NHT funded projects which directly address environmental issues are likely to have some benefit for the environment but, if projects are successful in changing behaviour, the bulk of benefits will come from induced activity. There are two sources of leverage or multiplier effects from NHT funding. The first is direct leverage, whereby NHT funding is matched by funding from other sources — state government, local government, other publicly funded organisations, or private sources including non-government organisations (NGOs). The

second source is indirect and relies on regional organisations or individuals investing their own resources in vegetation management, having been influenced by an NHT project.

What is needed is a way to measure the size of the multiplier effects of individual projects in order to identify those approaches that are most effective.

This is not, however, any easy task. Chart 4.2 outlines the sources of project multipliers. One issue for the federal government is the extent to which the NHT projects act as a catalyst for other tiers of government to fund complementary projects. This is represented in the first column in chart 4.2. This activity should be reflected in government records.

Chart 4.2 **Project multiplier effects**



The second column reflects private activity. This may be driven by pecuniary motives or by community spirit.

There are several ways to estimate outcomes.

- Surveys can indicate the penetration rates of different formal activities. CSIRO's National Tree Farm Survey (Nicoll and Dobbie 1996) recorded information on the sources of advice on tree planting. Of the 73 per cent of respondents who had received advice, 67 per cent came from state, territory or local government agencies, 22 per cent from Landcare, 17 per cent from nurseries, 13 per cent from other formal groups, and 11 per cent from Greening Australia.
- Counts of membership in voluntary organisations, and the number of branches and spread of organisations can indicate possible spin-offs from the formal projects. For example, a Roy Morgan survey conducted for Landcare Australia found that awareness of Landcare has grown from 11 per cent to 62 per cent in urban areas and from 40 per cent to 86 per cent in rural areas over the period from 1991 to 1994 (cited in Dumsday 1997).
- Contributions to voluntary organisations, financial and in-kind can be determined through surveys of the organisations.

4.1.4 Implications for indicators

We know very little about what makes people change their behaviour and protect or establish vegetation. And there is very little data available to change this lack of knowledge. Yet this is a critical link in the overall success or otherwise of the programs. Most industry representatives can recite a mantra of the impediments to the expansion of their industry, and farm forestry is no exception. These lists have been written down, expanded, and some solutions recommended and some even implemented. But the lists do not get to the issue of whether these are binding constraints, where removal will see a surge of activity, or whether they are a set of preconditions for activity. Many of the FFP projects, though fewer of the Bushcare projects, have been targeted at reducing or removing impediments.

But getting the preconditions in place is not a sufficient condition for adoption. And often things identified as preconditions — removal of an impediment or provision of an incentive — turn out not to be necessary for adoption. It is hard to develop indicators of the drivers of adoption when we do not know what are necessary and what are sufficient conditions for adoption. This suggests that the focus of the indicators should be on:

- measuring actual adoption, and with each measure
- recording a range of data on factors that may have influenced that change — knowledge of projects, source of knowledge, involvement in projects, NHT and other, types of projects, financial incentives, farm income, cash flow, costs, community activities, and so on.

Only then will there be sufficient data collected over time to inform us about the drivers of change — the preconditions and the catalysts for adoption.

4.2 Final outcomes: how are they valued?

Evaluation of programs does not necessarily require putting values on outcomes — qualitative judgments about meeting objectives are often sufficient. Reducing complex outcomes to dollar values is sometimes inappropriate and the error margins in such estimates are often very large. However, even if the true value cannot be estimated with much confidence, the process of thinking about the value of the outcome — in particular to the

broader community — is essential for efficient allocation of scarce resources (in this case taxpayer funds).

There are various methodologies available to estimate the value of the various final outcomes (see Wills 1997 for an overview). These outcomes have both use and non-use values.

- *Onsite use values* — Use values are usually associated with market values. The best approach is a bottom-up addition of the net benefits. Wood and agricultural production have market prices, and will have in the future. By applying market prices to new products and net yield improvements the value of the program's on site outputs can be estimated.
- *Off-site use values* — The two off-site uses are reduction in infrastructure costs and carbon sequestration. Cost based estimates are often used to reflect the value of reduction in infrastructure repair needs or avoided works. While carbon sequestration is not currently traded on markets carbon does not have an explicit price. But it could potentially be allocated and hence priced by markets, and modelling techniques are used to estimate this price.
- *Non-use values* — These are sometimes called intangibles, existence or option values. They derive from the knowledge that the asset — environmental or social — will exist in the future. The main non-use values are associated with the environmental outcomes, preserving our natural heritage for future generations and in its own right, and in sustainable production providing for a continuation of a rural lifestyle.

When estimating the value it must be the change due to the project or the induced actions that are measured and not the changes due to other factors. This requires knowledge of the physical outcome if the actions had not been taken. Often the value to production will be lower rates of yield loss due to slower rates of degradation. But the observed yield may still be rising due to additional inputs. Appropriate estimates of value need to take all these elements into account.

Many of the broad-based estimates of the cost of land degradation fail to take sufficient account of these issues. But they are useful in providing a background to establish the 'without' scenario. A brief overview of broad-based measures is provided, followed by more specific methodologies for assessing on-site, off-site and non-use values.

4.2.1 Broad based estimates

There have been a number of estimates of the cost of land and water degradation in Australia based on lost productivity. All estimates in this and the rest of the chapter are in the current dollars in the year of the report, unless otherwise stated.

- Eckersley (1989) estimated that land degradation is costing Australia \$600 million in lost agricultural production.
- Hall and Hyberg (1991) estimated the value of lost broadacre agricultural production in 1983–1984 was \$393 million.
- Price (1993) presents estimates of annual production losses of:
 - \$180 million for water logging;
 - \$80 million for erosion;
 - \$200 million for salinity;

\$300 million or soil acidity; and
\$200 million for loss of soil structure.

- MDBMC estimates the annual cost of production foregone to be in excess of \$65 million (1988 dollars). (Reported in Dumsday 1997.)
- DPIE (1993) estimated the cost of degradation based on yield losses from 'potential' land degradation as \$790 million in 1988–1989 prices. Three quarters of this was attributed to loss through soil structure decline.
- In Western Australia the value of production foregone due to soil erosion was estimated at \$609 million a year (Legislative Assembly, WA 1991).
- In NSW production foregone due to soil structure decline was estimated at \$14 million, soil acidification at \$100 million and total losses at \$250 million a year (EPA of NSW, 1993).
- In South Australia the annual loss due to soil structural degradation is estimated at \$60 million (SADA, 1991).

The concern with these estimates is that they:

- fail to take account of costs of measures to reduce degradation (understating cost);
- tend to value the lost productivity at market price, when the higher production might have lowered price (overstating price);
- may not subtract the cost of production avoided when areas are withdrawn from production (overstating cost);
- depend on estimates of degradation that are at best crude (CIE 1998 for further discussion).

There are several other approaches.

If farmers undertake the optional amount of soil degradation control then the marginal dollar spent on control will be equal to the value of production saved by the control. This suggests that the cost of control is a rough proxy for the value of production that would have been lost.

- Blyth and McCallum (1987) estimated the cost of repair and prevention of soil loss ranged from \$25 to \$100 per hectare for capital costs and \$1 to \$8 for annual costs.
- The results of the Collaborative Soil Conservation Study reported in Woods (1984) suggest that the cost of restoring land to its pre agricultural state in terms of water and wind erosion, was \$675 million (in 1997 dollars this is \$2.4 billion).

A more sophisticated approach recognises the difficulty in mapping the change in production to the changing land and water resource base. In fact, productivity has grown at an average of 2.5 per cent a year in the agricultural sector. Other inputs — fertiliser and water management requires, genetic improvements and so on — have maintained and increased yields despite increasing degradation. Gretton and Salma (1997) use an econometric model to isolate the effect of land and water degradation on farm profit. They estimate that the responsiveness of current production and profit to changing land degradation in NSW using survey estimates of degradation — aggregated to Statistical Local Areas, and ABARE data on farm profits and inputs. The survey identified 10 types of degradation — four are used in the study. For New South Wales a 1 per cent increase in soil structure decline was estimated to reduce profits by 0.29 per cent, while a 1 per cent increase in induced soil acidity reduced profits by 0.13 per cent. However, increases in dry land salinity and irrigation salinity were

estimated to increase profits at the margin as farmers increase crop and animal production, shifting to more intensive production on the better land. The results are tentative but the approach demonstrates considerable potential for sophisticated analysis when geo-referenced data is available.

These broad estimates provide a useful background to the aggregated estimates of the impact of the FFP and Bushcare on conservation outcomes. But as these two programs are part of the broader NHT Landcare and state programs, a bottom-up approach is required to assess the value of the FFP and Bushcare.

4.2.2 On-site use values

The value of wood and other tree products relative to other products that would have been produced (or alternative uses of the capital) and the value of changes in yields due to the actions taken can be estimated using existing market prices. In general current prices (average over a typical period) are used as a measure of future prices. However, where something is known about future changes in demand and supply conditions, economic models can be developed to incorporate this information to give better projections.

Wood and wood products

As the production lag is relatively long — 30 to 80 years for sawlogs, 5–20 years for pulp logs, 5–10 years for firewood and posts — the critical component in estimating the net present value is the price projections. Prices depend on total supply relative to total demand.

- For hardwood sawlogs demand is expected to rise relative to supply pushing up real prices in the future. The situation in softwood is not as severe, but some long term increase in price is also projected. Ryan (1994) estimated that in the Pacific Rim area, by 2000 there would be an annual short fall of 325 mm³.
- Demand for pulpwood is also likely to increase relative to supply. The paperless office is unlikely to become a reality for several decades, and even then the increasing incomes in the Asian region will support demand for paper.
- Costs of production and margin activities — such as transport and handling — also impact on the return to the grower (farm gate price). The current consensus is that farm forestry is viable if located within 100 kilometres of an existing (or potential) processor or port. However, falling transport costs and improved technology for on-farm value adding will raise the distance threshold over time. Most estimates of farm-gate price will err on the cautious side and assume no change in real costs of production or transport and handling.

The approach is highly standardised, requiring in addition to the price and cost parameters, estimate of the merchandisable wood volumes from thinnings and the final product.

The FARMTREE model (Loane 1991) combines all these factors in the first two columns in chart 4.3 to allow farmers to assess the potential return on growing trees on their farm. The model takes into account some of the bio-physical models to assess growth rates, and a variety of economic inputs such as distance to the nearest market. Such models can be very useful in estimating the expected rate of return from wood production as a result of farm forestry activities. This can assist in assessing the effectiveness of farm forestry programs.

However, as chart 4.3 suggests it is often the indirect costs and benefits that will be the decisive factors.

Other tree products

ACIL (1993) conducted farmer interviews in an attempt to quantify the financial returns from a list of possible economic uses listed in chapter 3. They were only able to obtain quantitative information for the following uses: wildflowers; ecotourism (camping, nature trails); timber for fences; firewood; brushwood; and native plant seed collection. The results obtained for these uses are given in table 3.1.

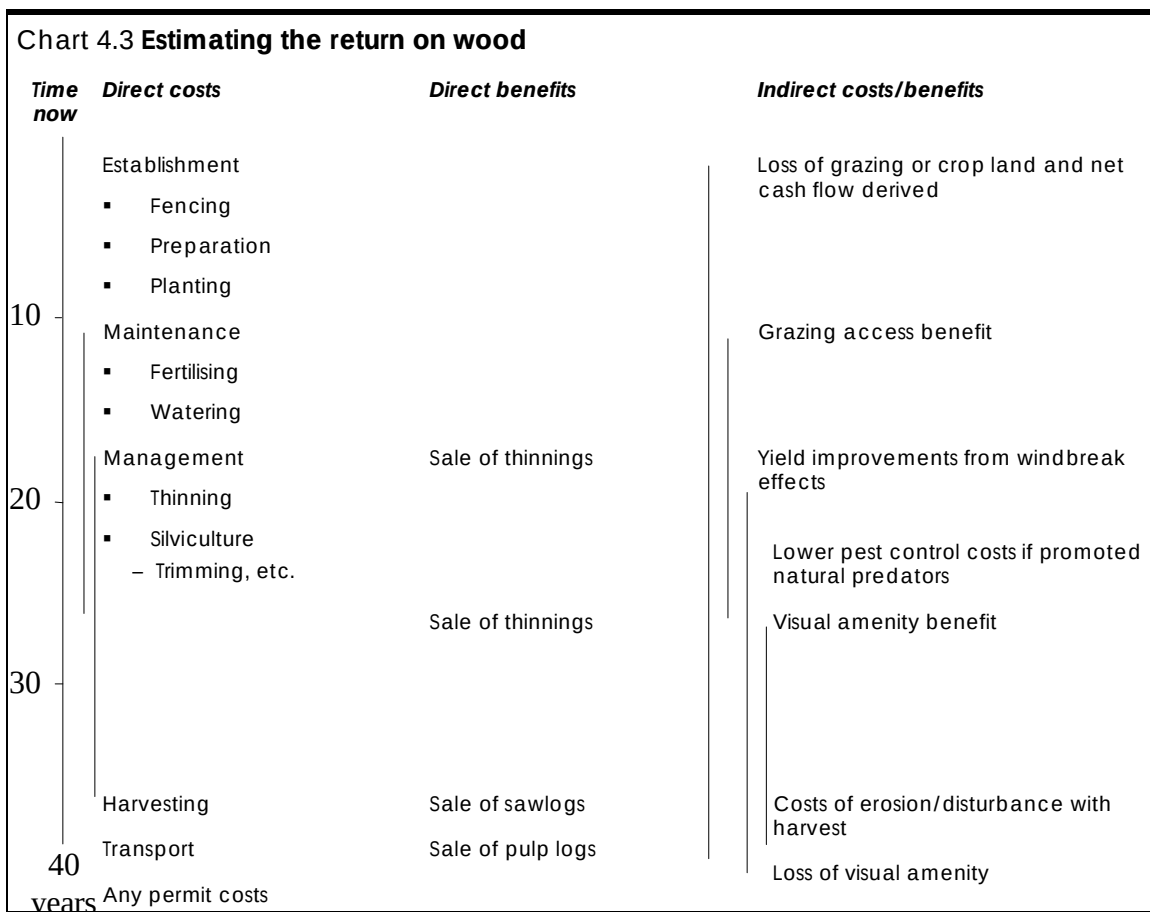


Table 4.1 Summary of net cash operating returns measured for sustainable remnant vegetation enterprises in the Western Australian wheatbelt compared with net cash returns from agricultural enterprises 1992-93

<i>Use</i>	<i>\$ per operator day worked</i>	<i>\$ per hectare</i>
Wildflower production	up to 248	124–232
Ecotourism	50–90	5–1,500
Timber products — fence posts (saving)	152–575	NA
Firewood	63	21
Brushwood	NA	10–100
Native plant seed collection	16–120	NA
Cropping	NA	150–244
Sheep (1992-93)	NA	12–31
Sheep (long term)	NA	26–95

Source: ACIL (1993).

According to Doran (personal communication), the tea tree industry – based on oils extracted from *Melaleuca* species – is currently booming, with about 5000 hectares of established plantations nation-wide growing by 20 per cent per year. Annual national production is currently about 300 tonnes of melaleuca oil worth about \$14 million at farm gate. Boronia is another native that has a highly profitable commercial application. It is grown mainly in Tasmania, but production is increasing in Western Australia. However, high processing costs require high oil yields and quality control is essential. For these reasons, while these crops will expand, it is unlikely that farmers will be able to benefit by including small areas as part of a diversified farm vegetation plan.

A similar approach to identifying benefits and costs for wood production can be taken to estimating the value of other tree products. Most of these do not face the considerable production lag of wood production.

- *Eucalyptus* oil is being produced in a number of areas in Australia.
- Wildflowers and foliage production earned \$30 million in export revenue in 1995-96. Some 20 per cent of this is bushpicked. Not all species suitable for sale could be combined in a farm forestry or Bushcare project, but there is some overlap.

Crop and stock yields

The most important component in estimating the value of the changes in crop and stock yields is estimating the actual impact on the yield. The difficulty in making such estimates was evident in chapter 3. However, once such models are available it is a relatively simple task to put economic values on the impact. All that is required is estimates of:

- change in yield over time;

- prices of the output over time;
- changes in any of the inputs associated with the change in yield; and
- costs of any of these inputs.

This approach allows a value to be placed on additional agricultural production resulting from the programs either directly or indirectly (see AACM for an example). A good example of the kind of benefit-cost assessment that can be conducted at a case study level is one on the net benefits at liming to address soil acidification problems (AACM, 1995). While this approach does tell us whether there was a better alternative, it does take the counterfactual or ‘without’ scenario as the basis for estimating change.

Whole of farm approaches

Farm management increasingly relies on sophisticated packages that assist farmers in selecting the optimal farm regime — what to grow, how to grow it, when to harvest and so on. There is at least one, and possibly more packages that include the benefits from landcare on yields in calculating the financial returns from alternative farming regimes. These packages can be used to assess the forgone alternatives after the fact as well as value of the regime adopted.

An early package is SOILEC, developed at LaTrobe University (Oram et al. 1989a, 1989b). This package draws on several models of the bio-physical processes by which trees and other activities control sheet and rill erosion and water table recharge. The package also predicts the impact of such reductions on crop and stock production using water balance models such as Soil Conservation in Agricultural Regions (SCAR). Putting values on these is the final step, which includes all the costs of the farming regime and the expected yields. What is really useful for farmers is that they can compare the short term (1 year) and long run (up to 50 year) financial returns under different farming regimes. The package requires quite detailed information on soils, topography and weather.

More recently other packages have been developed. The Agricultural Production Systems Research Unit in Queensland (Queensland Department of Primary Industries, CSIRO Tropical Agriculture and Queensland Department of Natural Resources) has developed a biophysical model that simulates crop production based on inputs including weather, soil, moisture, and other components of soil (APSRU, 1996). The focus is on broadscale farming systems of Queensland and Northern New South Wales — primarily grain/grazing — but cotton and sugarcane production are also modelled. A RIRDC project is underway to assist in delivering this program via the internet.

A major concern with these types of models is that they are too general and cannot capture the outcomes on any one farm accurately. While there is an element of truth in this it should not reduce the usefulness of models of this kind at either the broad or narrow level. At the broad level the models provide a very useful way to estimate the average and hence overall impact of the programs. And at the narrow level the package can be fine tuned to reflect the specific conditions on any one farm.

Focus on private returns

This section has focused on the returns to the landowner. Financial returns — long run and short run — are usually the most powerful incentive for farmers to change behaviour. Unless the total return (pecuniary and nonpecuniary) on farm forestry and Bushcare is higher than returns on alternatives few farmers will adopt the techniques despite all the skill enhancement and awareness of problems. In many cases investment in vegetation is seen as the best option for long term private outcomes. But the focus is often on the short run returns. Research at Charles Sturt University on the benefits from retaining remnant vegetation showed a mixed outcome with some farmers benefiting considerably from use values. Others didn't derive net use benefits, and all indicated that stricter controls on use of remnants — grazing, fire wood and so on — would negate current use benefits. However, the existence of remnants on farms did not influence their value, suggesting that long term benefits are not perceived (Lockwood and Carberry, 1998; Walpole et al 1998 and Miles et al 1998). And in some cases private returns will not be sufficient for behaviour to change. Where there are substantial benefits to the broader community this will result in sub-optimal outcomes.

An example given in Oram et al. (1991) illustrates the divergence between public and private return — but how the best private solution can also be at substantial public benefit. For an area in north-east Victoria on two types of soils, planting native trees as part of the agricultural regime had the best conservation outcome in terms of reduced soil loss and lower recharge, but the worst impact on farmer income. Farmers, unless offered additional inducements, would not plant native trees. But there were changes to traditional activities that reduced recharge and soil loss and provided higher financial returns. And when both private and public benefits were taken into account these regimes were still the best choice for maximising total benefit.

The lesson for evaluation is useful. The best environmental outcome may not give the best economic outcome even when public benefits are included. This is a good reason why it is important to ensure that all public benefits are included in assessment even if difficult to value accurately. Ignoring such benefits can lead to poor decisions when the measured benefits of alternatives are relatively close. Similarly, private costs must be factored into net benefit estimates even when the focus is on public benefit. In addition, the possibility of low probability but very high cost events should not be ignored in assessment.

4.2.3 Off-site use values: carbon sequestration

Global warming falls into the category of low probability but potentially high cost events, in addition to more predictable impacts. Perhaps the most important off-site use value of revegetation and protecting remnants is in their carbon sequestration.

It is widely accepted that the clearing of the earth's vegetation has contributed to rapidly accelerating levels of carbon dioxide in the atmosphere. Increased levels of carbon dioxide produce an enhanced greenhouse effect. There is international consensus that this will raise the temperature of the earth, and result in changing weather patterns, although no one climatic change scenario has been accepted. Models of the complex physical processes provide a range of possible outcomes, from mild to extreme, indicating at least a chance of a very high cost event as a result of the effect (Whetton et al. 1996 discuss some possible outcomes for Australia and New Zealand).

This may result in a variety of social and economic impacts including:

- increasing health costs — for example from heatwaves, increase in various ‘tropical’ diseases, in particular malaria;
- greater frequency and unpredictability of natural disaster events with cost to human life and economic infrastructure;
- changes in agricultural productivity with loss of some traditional agricultural areas, and possible gain of others (see Reilly 1997, Campbell et al. 1996, Sutherst et al. 1996, and Mitchell and Williams 1996 for a discussion of possible impacts on Australian agriculture); and
- loss of biodiversity as species relocation and evolution cannot keep pace with an increasing pace of climate change (see Mitchell and Williams 1996, Moore and Smith 1996 for a discussion of possible impacts on Australian native flora and fauna).

The potential socioeconomic cost is unknown, but calculations based on predictable damages range from 1 to 2.5 per cent of GDP for industrialised countries for a doubling of the atmospheric concentrations of carbon dioxide. For developing countries the costs are likely to be higher as a share of GDP (Decanio 1997, from Cline 1992, Fankhauser 1995, Nordhaus 1991, Titus 1992 and Toll 1995). This gives a minimum estimate for the cost of not doing anything.

The cost of reducing emissions has also been estimated. McKibbin et al. 1994 estimate that the cost of reducing Australia’s emissions to 1990 by 2005 is 0.93 per cent of GDP in 2005. Fisher et al. have a slightly higher estimate of a little over 1 per cent of GNE to stabilise carbon dioxide emissions at 1990 levels by 2010. These estimates are in line with estimates of the cost to the United States of reducing emissions to 20 per cent below 1990 levels by 2010 ranging from 0.9 per cent to 1.7 per cent of GDP (IPCC 1996).

Comparing the cost of doing something to not doing anything, most would find in favour of doing something, although the cost and benefit numbers presented here are not directly comparable. Two other aspects tilt the balance in favour of action.

- There are believed to be a number of no net cost options for reducing carbon dioxide emissions. For example Anderson and McKibbin (1997) have estimated that removal of distortions in the global coal market would reduce carbon dioxide emissions by almost 8 per cent, and provide substantial other benefits. IPCC (1996) review a number of studies on such no cost options.
- There are possible very high cost events that could be associated with climate change. These are the collapse of the West Antarctic Ice Sheet, a runaway greenhouse effect, and structural changes in the ocean currents that could see massive release of carbon dioxide. Each of these events would impose enormous costs. While their probability may be judged to be very low, it is not zero. The precautionary principle suggests the inclusion of such low probability high cost events in benefit cost calculation. This is also true for land degradation though not on the scale of greenhouse gas emission control.

The global community has accepted the evidence and attempts are being made to reduce the level of greenhouse gas emissions. In 1997 the developed countries signed the Kyoto Protocol which commits them to achieve emission targets by 2008–12. The targets are set relative to countries’ 1990 emission levels. Australia was allowed an 8 per cent increase over

this level. It is likely that to achieve these levels an emission tax, or tradeable emission permits will be instituted.

Prices for carbon sequestration

The estimates of the tax required to reduce Australian emissions to 1990 levels vary widely. ABARE (1994) estimated a tax of over \$300 per tonne of carbon dioxide would be required. McKibbin et al. (1994) estimated a tax of \$13.80 (1994\$) would be sufficient to achieve 1990 levels. More recent in-house estimates are for a tax rising from \$3 in 1999 to \$18 by 2020 (Pearce and McKibbin, personal communication). The estimated tax is a reasonable proxy for the price of a tonne of carbon dioxide under a trading scheme, although if the trading scheme is international the relevant tax is the average global tax, which may well be lower.

Value of carbon sinks

There is considerable activity in developing market instruments for the sale of carbon sinks. There are a number of methods for measuring the carbon sequestered on an annual and long-term basis (for example AACM 1997 discussed in chapter 3). Market activity requires acceptance of a single methodology for evaluation. But trading in carbon permits is likely to be very much a reality in the future.

The programs provide two sources for carbon sinks. The first is through reducing clearing of native vegetation. Carbon is released from a site for a 20 year period after clearing, which results in around 180 tonnes of carbon dioxide being released from each cleared hectare of land (NGGIC reported in WWW Australia 1997). If a tax of \$10 a tonne is imposed on carbon dioxide, then the benefit of not clearing is roughly the tax equivalent, \$1800 a hectare, (\$1400 at a discount rate of 8 per cent). This could be compared with the benefit of clearing that was estimated in 1991 at around \$22 a hectare a year in the western division in NSW (Hassall and Associates 1991). At an 8 per cent this equates to a present value of \$275 at hectare. If farmers can sell areas as carbon sinks then the financial return on not clearing may well outweigh that on clearing.

The second source of carbon sequestration is through the planting of trees. In particular, trees for sawlogs, or permanent revegetation, where the carbon is sequestered for a long period of time, could be sold as carbon sinks. Estimates are that plantations — *Pinus radiata* or *Eucalyptus globulus* — take up around 7 tonnes of carbon dioxide per hectare per year. (NGGIC 1994). If permits sold at \$10 a tonne, then a hectare of trees would provide a credit worth \$70 a year, at least while in the rapid growth stages.

4.2.4 Off-site use values: infrastructure maintenance costs

There have been a number of estimates of the cost of repairs, additional maintenance and water treatment required due to salinity and erosion. These are usually made by adding the costs of actual repairs or treatment, and may overstate the cost if routine maintenance costs are included. However, as local councils and others subject to the problem do not always undertake the required repairs, the cost could well be understated. Most estimates should be regarded as indicative only.

- Watson et al. (1995) reports the results of an ABARE survey of local councils which asked about the cost of repairing infrastructure damaged by salinity and or rising water tables in the Murray Darling Basin over a 12 month period. The costs of repairs to roads and bridges, water supply systems, parks and gardens, sewerage systems, public buildings and other facilities was \$7.9 million. Of this \$6.8 was on roads and bridges.
- Oliver et al (1996) surveyed councils in the Murray Darling Basin Commission about their expenditures on repairs and maintenance of infrastructure. Over the 12 month period (either 1993–94 or 1993) responding councils reported spending \$8.2 million due to salinity or rising watertables, \$7.1 million of this was on roads and bridges.
- Murray Darling Basin Commission (MDBC) (1995) estimated that each hectare of trees saved \$30 in reduced damage to infrastructure and \$25 in reduced water treatment costs.
- MDBC (1994) estimated that the cost of increasing salinity in the Murray River was \$112 000 per electrical conductivity unit. They have estimated that river salinity imposes a cost of \$37 million a year mainly on urban and industrial users of water in Adelaide.
- In the Eppalock Catchment Soil Conservation Project (1978) lower maintenance costs for roads, bridges and water supply were estimated to provide a saving of between \$30 000 and \$15 000 a year (1974-75 prices).
- Dumsday and Oram (1990) report estimate of the cost of salinity in Victoria at \$18.8 million. This is made up of \$5.5 million in lost production from dryland salinity, \$6 million from lost production from irrigation salinity and \$7.3 million in downstream water quality effects.
- Greig and Devonshire (1981) estimated for 56 Victorian catchments that the cost of land clearing in terms of increased stream salinity was \$4.40 a hectare a year.
- Eckersley (1989) put the cost of off-site maintenance and treatment of degraded land as high as \$1.4 billion a year.
- Peck et al. (1983) estimated the costs of induced dryland salinity at \$87 million (1982 prices). It is made up of:
 - \$22 million in agricultural losses;
 - \$10 million in land salinisation abatement costs;
 - \$36 million in damage to water supplies;
 - \$13 million in treatment costs; and
 - \$6 million in research and monitoring costs.
- In the Yass River Catchment the cost of treating turbidity in Yass River water for domestic consumption was \$150 000 per annum in 1992 (Russell et al. 1991; NSW Department of Conservation and Land Management 1992). The storage capacity of the Yass Weir has been reduced by 25 per cent over the last 60 years. To compensate the dam wall has been raised at a cost of \$200 000. The construction of a multi-level intake structure on the dam wall to draw in water at various levels cost a further \$250 000.

4.2.5 Other off-site use values

There are a wide variety of off-site non-agricultural use values associated with the outcomes of the Bushcare and farm forestry programs both in rural and urban areas. These include:

- improving the quality of venues for recreation;
- enhancing the aesthetic attributes of the landscape — although the value placed on particular attributes may differ between individuals. Work at the University of Melbourne Institute of Land and Food Resources by Kathryn Williams examining farmer's attitudes

to different landscape types found considerable differences in preferences. Interestingly, farmers that prefer more open and smooth landscapes (lower ecological naturalness) are also less willing to promote native vegetation protection (Williams, personal communication). Little work has been done to try and understand what attributes contribute most to the average aesthetic value at the broader landscape level. See Chapman (1990) and Abel et al (1997) for a discussion of attributes that contribute to the aesthetic value of farms;

- pollution control — vegetation can be managed to reduce noise and dust pollution in addition to previously discussed contributions to pest control and carbon sequestration. The value of using vegetation as a management tool depends on possible alternatives, but the contribution should still be included in an assessment of benefits. If alternative control mechanisms are available, the value is the cost saving of the usually multipurpose vegetation. Includes assessment of values of improving human health are fraught with difficulty. While there are a variety of methods available to assess such benefits — cost of illness, risk reduction, statistical life calculations (see Reichard et al (1990) O’Neil and Rauchen (1990) and Sharefkin et al 1984) — this is not an area that is only likely to be of interest in the case of a project designed to deliver health benefits for which no other feasible solutions were available.

There are several methodologies for estimating the value of an environmental asset for recreation and aesthetics appreciation — the main approaches being travel cost, and hedonic pricing.

Travel cost approach

The travel cost method measures the associated costs of undertaking a recreational activity. It is the standard measure used to estimate the recreational value of national parks. The motivation for the measure is that people will pay up to their value on the recreational activity to enjoy the activity. For example, the value of going for a sail on the bay is at least equal to the cost of travelling to the bay, renting a boat (or the amortised cost of the boat and its up-keep), and travelling home. This is an approximation of the opportunity cost of the activity — the saving of not undertaking the activity. It assumes that the return on not undertaking the activity is zero

There has been considerable work done estimating the recreational value of National Parks. The value of the Grampians for recreational uses has been estimated using the travel cost method at \$18 per visitor per day (Sturgess 1994). Beale (1995) estimates the consumer surplus for the use value of visits to Carnarvon Gorge National Park at \$2.4 million a year. Further work, by Chotikapanich and Griffiths (1998), has shown that the value could be as much as six times this amount, depending on the functional form of people’s preferences as this influences how much surplus people enjoy at any given price. This difference demonstrates some of the difficulties that arise using the methodology, and in particular estimates of consumer surplus as measures of value.

- It is not clear what the recreational value of the farm forestry to Bushcare programs has been. This value is likely to be more relevant to other programs in the NHT such as the National Rivercare Program.

Hedonic pricing methods

The hedonic pricing method estimates the value of a feature of a landscape by comparing the values of a landscape with the feature to one without. It uses market values in making the comparison, thus is limited to uses where market values are available. For example, the value of trees on a farm can be estimated from the price the farm sells for compared with an identical property that does not have the trees. If the trees add to the productive capacity of the farm the difference should be equal to the discounted value of the additional stream of income arising from the trees. But if the trees only contribute to aesthetics, then the difference in value can be accounted by that alone.

There is some evidence that farms with a higher area under trees attract a price premium. A study in Victoria referred to by Russell et al. (1991) found that the land values of properties with existing tree cover were up to 10 per cent higher than those with little or no tree cover. However, as discussed earlier, a study in New South Wales western districts using hedonic pricing techniques found no significant differences in property sale prices due to the amount of remnant vegetation on the property (Lockwood and Carberry 1998; Walpole et al 1998 and Miles et al 1998).

4.2.6 Non-use values

There are two main methodologies for estimating the non-use values. Both rely on surveys to get people to reveal their willingness to pay for the existence of something.

Contingent valuation

The contingent valuation method attempts to get people to reveal their willingness to pay for a good or service (or their willingness to be compensated for the removal of the good or service). This methodology has been used extensively in estimating non-use values associated with environmental changes. The approach effectively measures consumer surplus rather than price. There is an extensive literature on the problems associated with contingent valuation, the main ones being the specificity of the measurement to the situation described in the survey, and the incentives for gaming by respondents. The first problem reduces the ability to apply estimates from this approach to other situations, and the second introduces bias into the estimates. However, careful construction and use of the surveys make this methodology an important part of the evaluation toolbox.

Contingent valuation has been used extensively in Australia to estimate the values of natural areas. Several well known examples are:

- Coronation Hill adjacent to Kakadu National Park (Imber et al. 1991);
- the Great South Eastern Forests where use benefits were estimated at just under \$1 million, while existence value was estimated at \$43.50 per household for the median household (RAC 1992); and
- Hundloe et al. (1990) who estimated that on average members of the Australian population were willing to pay \$204 to protect Fraser Island. Visitors were willing to pay \$316, indicating that the use value is around \$130 and the non-use value \$187.

Less well known are uses of the techniques in estimating the willingness to pay for soil conservation and protecting our waterways.

- Carlos (1991b) surveyed households in Yass to assess their willingness to pay for improved water quality. On average they were willing to pay up to \$25 a year.
- Sinden (1987) conducted a survey in Sydney which found that people were willing, on average, to pay 10.6 cents extra for a loaf of bread if the wheat was grown using land conservation techniques.
- Dragovitch (1990, 1991) also surveyed Sydney households on the relative importance of soil erosion. He found that 79 per cent of respondents were willing to pay a surcharge on bread to stop erosion.

The technique has also been used to estimate existence values:

- Bennett (1984) estimated that the existence value of the Nadgee Nature Reserve to Canberra residents as \$2 a year an adult.
- An estimate for the preservation value of the National Estate Forest in South East Australia is \$22 per household per year (in Lockwood and DeLacy 1992).
- Recently Bennett et al. (1997) estimated a median willingness to pay of \$140 a household to protect Tilley Swamp and the Coorong in South Australia by building a pipeline to divert fresh water run-off to the ocean.

Care should be taken in interpreting willingness to pay estimates from contingent valuation as they are generally relevant only in the context in which the question was framed, and the time at which it was asked. They cannot be added, as each is considered independently of the others unless the survey questions are framed in the context of making other payments. For cautions on the interpretation of contingent valuation estimates see Bennett et al. 1998, Wilks 1990.

Choice modelling

Choice modelling has been used extensively in estimating the willingness to tradeoff different features of transport systems and urban development. In recent years it has been used for estimating the willingness to tradeoff different attributes of the environment (see Adamowicz et al. 1998, and University of NSW choice modelling research report series). By including one attribute that has a natural interpretation in dollars — such as the cost of water, or a contribution to a conservation trust fund — estimates of the values of different attributes can be estimated. The total value of an option is the sum of the values of its attributes. While these measures are contingent on the base option presented in the surveys they are more flexible in valuing alternatives. This approach is particularly useful if there are interactions between the attributes that influence the value placed on both attributes. It also provides estimates that can be used to test how the overall value placed on a venue changes with changes in its attributes.

These techniques have only recently begun to be used in estimating conservation values.

- CIE used to technique to estimate the value of improving the environmental flows in rivers. On average people were willing to pay an extra \$45 for water to maintain environmental flows. People were willing to pay an extra \$5 a year on their water bills to preserve habitat for uncommon species in the ACT region that might be threatened by new dams (Centre for International Economics 1997).

- Rolfe et al (1998) used the technique to estimate the value of different features of forest conservation such as country of location, area protected, rarity, and benefits to local people. They conducted several surveys, trialling different combinations of attributes.
- A project is currently under way on estimating the values associated with the outcomes of different tree clearing regulations. Some of the attributes to be valued are the endangered species, the population of non-threatened native species, the level of local employment and the ecosystem health (Bennett, personal communication). This project is part of the EA/LWRRDC remnant vegetation program.

Choice modelling has the potential to allow a range of program outcomes to be valued. In particular it can be used to assess the relative willingness to tradeoff various environmental outcomes with economic and social outcomes. However, as with all survey techniques, estimates are only relevant for the period in which they are estimated.

Benefit transfer

However, as long as willingness to pay estimates from either methodology are treated with due caution they can be useful in providing some overall indication of the value that might be placed on the non-use outcomes of a project and program. The Environmental Protection Agency (EPA) of NSW is compiling a database of estimates of non-market and non-use values (EPA 1995). This database makes easily accessible a range of values associated with a range of situations. Where similar situations arise it is reasonable to use estimated value as a first pass guess at the likely value that would be put on the non-market use and/or non-use outcomes. Where inclusion of the value results in a clear indication of the net benefit to decision makers performing expensive additional surveys to estimate these values more accurately is probably of little value (see Read and Sturges 1998 for a discussion.) However, where decisions are not clear better information is required. Where no similar situations are available on the database, a survey to assess values will add to not only the particular assessment, but to the toolbox of information for other assessments.

4.2.7 Implications for valuing the outcomes of the programs

There are a variety of techniques available for attaching values to outcomes. They range in how broadly they can be applied and in the degree of uncertainty in the estimate. As a guide:

- market prices are widely applicable, but the degree of uncertainty increases with the forecast horizon and the volatility in the market;
- actual costs used as proxies — travel cost, hedonic pricing methods, infrastructure repair costs — are highly location specific, but if collected carefully should be reasonably accurate;
- willingness to pay estimates from contingent valuation surveys are highly situation specific, and are not additive. They do change over time, but usually big changes can be identified;
- willingness to tradeoff estimates from choice modelling have some potential to be more generally applicable. As with contingent valuation estimates they will change over time as attitudes change; and
- a database of estimates of non-market values is available to provide a first guess at the magnitude of the benefit. Using such information can avoid expensive specific

estimations where the situations are sufficiently similar and the margins sufficiently large for the required purpose of the overall valuation.

5 Towards indicators – existing indicator programs

5.1 SoE reporting

The following background to the National SoE reporting process is provided by Saunders et al. (1998):

The Commonwealth state of the Environment Reporting system supports the *National Strategy for Ecologically Sustainable Development* and helps Australia meet its international obligations, such as those under *Agenda 21* and the OECD environmental performance reviews. The first independent and comprehensive assessment of Australia's environment, *Australia: State of the Environment 1996* was released by the Commonwealth Environment Minister in September of that year. ... The next step in the evolution of the reporting system is to develop a set of environmental indicators that, properly monitored, will help us track the condition of Australia's environment and the human activities that affect it. (p. III)

In order to help with this process, Environment Australia commissioned a series of consultancies to arrive at a set of nationally agreed indicators for SoE reporting. To date, indicators have been developed for biodiversity (Saunders et al. 1998), land (Hamblin 1998), inland waters (Fairweather and Napier 1998) and estuaries and the sea (Ward et al. 1998). Indicators for the atmosphere, natural and cultural heritage and human settlements have been developed about six months behind the first four themes (Saunders et al. 1998).

5.1.1 Scale of data collection

Saunders et al. (1998) suggest:

The scale at which the information is needed for management purposes dictates the scales (spatial and temporal) at which the monitoring program must resolve changes in each indicator. (p. 5)

In other words, the scale at which data is collected will depend upon the detail of information required for management and reporting. However, as alluded to by Lloyd (1996) in a review of thirteen Australian State of the Environment reports, this would appear to be a nice idea in theory, but could prove extremely difficult to operationalise. For instance, Lloyd (1996) found that:

although nearly all the reports acknowledged the importance of using agreed indicators few attempted to do so in a manner that would allow long term trends to be identified. One of the reasons for the non-use of indicators was that there was no agreed model or theoretical framework on which the analysis could be based. (p. 151)

Furthermore, all the SoE reports that were reviewed found:

...paucity of effective monitoring programs and of long term data, especially those data referring to the state or condition of the environment. (p. 161)

5.1.2 Reporting level

Commonwealth government

Saunders et al. (1998) state:

Australia: state of the environment 1996 is the first stage of an ongoing evaluation of how Australia is managing its environment and meeting its international commitments in relation

to the environment. Subsequent state of the environment reports will assess how the environment, or elements of it, have changed over time, and the efficacy of the responses to the pressures on the environment. The next national SoE report is due in 2001, consistent with regular reporting cycle of four to five years. (pp. 4–5)

State and territory government

Commonwealth of Australia (1994) report:

Most State and Territory governments have developed state of the environment reporting programs. Reports have now been published by the Australian Capital Territory, Victorian, South Australian, Western Australian and New South Wales Governments. South Australia, New South Wales, the Australian Capital Territory and Tasmania have established programs for regular reporting. In New South Wales state of the environment reporting is required under the Protection of the Environment Administration Act 1991, in the Australian Capital Territory it is covered under the Commissioner for the Environment Act 1993, and in Tasmania it is covered by the State Policies and Projects Act 1993.

Local government

Commonwealth of Australia (1994) report:

Through Agenda 21 and through specific legislation (for example, under the New South Wales Local Government Act 1993 and the Queensland Local Government (Planning and Environment) Act 1990) local governments are beginning to inherit environment reporting responsibilities. Some local governments (for example, Shoalhaven and Coffs Harbour) have prepared state of the environment reports as part of local or regional conservation management strategies. Others (for example, the inner metropolitan councils of Melbourne) have started to investigate reporting frameworks and potential environmental indicators.

5.2 National Land and Water Resources Audit

The National Land and Water Resources Audit is a program of the Natural Heritage Trust. Commonwealth of Australia (1998) state that the objectives of the Audit are to facilitate improved decision-making on land and water resource management by:

- providing a clear understanding of the status of, and changes in, the nation's land and water resources and implications for their sustainable use;
- providing an interpretation of the costs and benefits (economic, environmental and social) of land and water resource change and any remedial actions;
- developing a national information system of compatible and readily-accessible land and water data;
- producing national land and water (surface and groundwater) assessments as integrated components of the Audit;
- ensuring integration with, and collaboration between, other relevant initiatives; and
- providing a framework for monitoring Australia's land and water resources in an ongoing and structured way.

5.2.1 Scale of data collection

According to Commonwealth of Australia (1998), the National Audit will collect information on the value of our:

natural resources, and on uses such as agricultural production, rates of land degradation, trends in water quality, water quantity, and status of vegetation resources. (p. 3)

Commonwealth of Australia (1998) suggest that the primary data will be stored at as fine a scale as possible, with emphasis on scientific integrity and consistency through time and across space. However, they note that scales are likely to vary in order to reflect both the scale at which the primary data is most appropriately interpreted, as well as the scale at which management decisions are likely to be made for that particular resource attribute.

5.2.2 Reporting level

Commonwealth of Australia (1998) report that:

Data will be collated incrementally across Australia for the whole range of Audit issues in order to build up a picture of the nationwide status. (p. 3)

5.3 Montreal process

Commonwealth of Australia (1997) state:

The history of the Montreal Process follows on from the UN Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992 and began when Canada convened an International Seminar of Experts on sustainable Development of Boreal and Temperate Forests. The seminar, held in Montreal, Canada, in September 1993 focused specifically on the development of criteria and indicators for the sustainable management of temperate and boreal forests and provided the conceptual basis for subsequent regional and international work on criteria and indicators.

The initiative led to the formation in June 1994 of the Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests, also known as the Montreal Process Working Group. (p. V)

The Montreal Process Working Group developed a criteria and indicator framework in 1995 to provide a common understanding of what is meant by sustainable forest management (Commonwealth of Australia 1997). The details of which are as follows:

The first six criteria deal specifically with forest conditions, attributes or functions, and the values or benefits associated with the environmental and socioeconomic goods and services that forests provide. The seventh criterion relates to the overall policy framework of a country that can facilitate the conservation and sustainable management of forests. (p. V)

In short, the aim of the criteria and indicators are to provide:

... tools for assessing national trends in forest conditions and management, and provide a common framework for describing, monitoring and evaluating progress towards sustainability at the country level. (p. V)

The report prepared by Commonwealth of Australia (1997) titled *Australia's First Approximation Report for the Montreal Process* is the first time Australia has attempted to report against the criteria and indicators agreed by the Montreal Process Working Group in 1995.

5.3.1 Scale of data collection

As noted by Commonwealth of Australia (1997), Australian forest management is currently being strategically reviewed through a regional forest agreement process. It is hoped that this process will provide:

... criteria for a national comprehensive, adequate and representative forest conservation reserve system flexibly implemented, security of resource access provided to forest industries and the implementation of improved monitoring based on criteria and indicators. (p. 100)

However, the preparation of the report *Australia's First Approximation Report for the Montreal Process* identified a number of issues relating to data adequacy and the applicability of indicators (Commonwealth of Australia 1997). These were:

- lack of consistency of data collection and format between States and Territories;
- different methods of data collection and collation for different land tenures; and
- different levels of data availability depending on forest type, with the commercial forest types generally having more data available at a finer level of resolution than for non-commercial types.

Furthermore, Commonwealth of Australia (1997) report that:

... not unexpectedly the indicators as they stand and the data provided in this report are not sufficient to allow a definitive conclusion to be reached about the sustainability of forest management in Australia as a whole, particularly for some tenures of forested land. (p. 101)

5.3.2 Reporting level

The reporting level of Australia's commitment to the Montreal Process is clearly at a national level. An example of the conclusions reached in the report *Australia's First Approximation Report for the Montreal Process* are as follows:

- Australia has on average 11 per cent of its forests and woodlands in nature conservation reserves, including 23 per cent of closed forests and 16 per cent of open forests;
- nationally, timber yields are now below sustainable levels and all State and Territory governments have either achieved sustainable yields or have adopted plans to work towards sustainable yields;
- major forest health concerns caused by air pollution do not affect Australian forests to any significant extent; and
- available data suggests that managed forests and woodlands are a net sink of carbon (Commonwealth of Australia 1997; p. 100).

5.4 Indicators developed by the Standing Committee on Agriculture and Resource Management

The Standing Committee on Agriculture and Resource Management (SCARM) and its predecessor, the Standing Committee on Agriculture (SCA), initiated four sequential projects associated with the development of indicators to monitor the sustainability of agriculture in Australia (SCARM, 1998). The objectives and/or achievements of these projects have been summarized in SCARM (1998) and provide the basis for the brief description given here.

The first project (SCA, 1991) developed five guiding principles to assess the level of sustainability achieved in Australian agriculture. This was followed by the second study (SCARM 1993) in which four key indicators and 12 attributes for assessing agricultural sustainability were proposed. A pilot feasibility study (the third project, 1994-1995) evaluated the proposed indicators and attributes in six diverse regions in which the broad types of farming systems used in Australia were represented (SLWRMC, 1996). In this study, scientists from the Commonwealth and State agencies assessed the validity, utility and applicability of each attribute. According to SCARM (1998):

'results from the pilot study were encouraging, although the availability and quality of regularly collected, regional data emerged as a key issue that could hinder future progress for some attributes' (p. 4).

The National Collaborative Project on Indicators for Sustainable Agriculture (NCPISA) was established by the Standing Committee on Agriculture and Resource Management (SCARM) in 1995. This was the last of the four projects. The two tasks of this project were to:

- ‘finalise the technical development of the agreed indicators and attributes, and
- assemble relevant data and provide the first national report on the sustainability of Australian agriculture, including trend analysis within the past decade.’

5.4.1 Scale of data collection

The five key indicators and 19 attributes examined by the National Collaborative Project on Indicators for Sustainable Agriculture are listed in table 5.1.

Table 5.1 Indicators and attributes examined by the National Collaborative Project on Indicators for Sustainable Agriculture

<i>Indicator</i>	<i>Attribute</i>
Long term real net farm income	▪ Real net farm income ▪ Total factor productivity ▪ Farmers' terms of trade ▪ Average real net farm income ▪ Debt servicing ratio
Natural resource condition	▪ Nutrient balance: P and N ▪ Soil condition: acidity and sodicity ▪ Rangeland condition and trend ▪ Agricultural plant species diversity ▪ Water utilisation by vegetation
Off-site environmental impacts	▪ Chemical residues in products ▪ Salinity in streams ▪ Dust storm index ▪ Impact of agriculture on native vegetation
Managerial skills	▪ Level of farmer education ▪ Extent of participation in training and Landcare ▪ Implementation of sustainable practices
Socioeconomic impacts	▪ Age structure of the agricultural workforce ▪ Access to key services

Most attributes required the development and testing of new methodologies to enable use of available data and to ensure the findings could be unambiguously interpreted. Since use was made of existing data, the scale at which the data were collected varied between the indicators.

5.4.2 Reporting level

The project did not cover the full range of possible attributes as a result of resource and data limitations. Those covered are reported at the national and regional levels, where regions used are the 11 agroecological regions. The main focus was to report trends over time, mostly over the last decade, for different areas. The report on the project (SCARM, 1998) provides some broad conclusions from the trends reported.

5.5 Other indicator programs

Walker (1998) reviews recent attempts at developing and using indicators.

He lists key components that should be included in an indicator monitoring program, and he proposes a number of key indicators of catchment health at the farm and local scale. These are divided into three sets: biophysical condition; biophysical trends; and productivity/financial performance/quality trends.

5.6 Summary

Indicators are being developed for state of the environment reporting by local governments, States and Territories and nationally. However, there is not yet an agreed set of indicators that will be reported on by all jurisdictions.

The National Land and Water Resources Audit has commenced operations to report on 7 themes: dryland salinity; vegetation cover, condition and use; rangelands monitoring; land use change, productivity, diversity and sustainability of agricultural enterprises; capacity of, and opportunity for, farmers and other natural resource managers to implement change; and river, estuary, catchment and landscape health. Reporting timeframes vary from December 1999 to January 2001. However, no indicators have yet been developed for the seven themes being covered.

The Montreal Process involves the development of criteria and indicators for assessing the sustainability of the management of Australia's forests. Under this process indicators have been specified and are being developed currently.

6 Conclusions

This literature review explores the current state of knowledge on vegetation management processes and, specifically, the current understanding of links between actions taken and final outcomes. There are four broad areas investigated in the review.

- *Biophysical processes for attaining conservation outcomes:* Do on ground actions, such as establishing vegetation and/or protecting remnant vegetation, produce desired *outcomes*, such as reducing water tables and salinity, improving soil conservation and water quality, and protecting biodiversity?
- *Biophysical processes for attaining sustainable production.* Do conservation outcomes and other actions impact on agricultural productivity and sustainability? Are there indirect link, such as through the impacts on infrastructure?
- *Socioeconomic processes.* What are the links between project outputs involving people and institutions, such as training or regional land management plans, and on-ground actions by land managers? How can such links be measured?
- *Value to farmers and the broader community* of Bushcare and the FFP and their project outcomes?

This Literature Review has found that there is considerable uncertainty about the links between on-ground actions and conservation outcomes (summarised in Chart 2.2). Further investigation of the biophysical processes for dryland salinity control, in particular, is required.

- On-ground actions involving vegetation and conservation outcomes can improve agricultural productivity but quantification of the effects is difficult (see Chart 3.2).
- Links between subprograms or projects aimed at people and communities and changes in actual behaviour and adoption of good vegetation management practices are tenuous. In general, however, there is some evidence that participation in training and landcare groups does lead to the adoption of more sustainable management practices.
- Where physical relationships can be identified, valuing final outcomes which have a market price presents few difficulties. The real difficulties lie in valuing outcomes which do not have market values. Techniques such as choice modelling or contingency valuation can be used to value these non-market outcomes such as improved recreational opportunities, aesthetics or biodiversity.

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