ECOSYSTEM SERVICES PROJECT

NATURAL VALUES

Exploring Options for Enhancing Ecosystem Services in the Goulburn Broken Catchment

PEOPLE ▸ ENVIRONMENTS ▸ VALUES ▸ OPPORTUNITIES

In the Goulburn Broken Catchment, the Ecosystem Services Project is a collaborative effort by the following organisations:

THE MYER FOUNDATION

The Sidney Myer Centenary Celebration
1899-1999

CSIRO

GOULBURN
BROKEN
CATCHMENT
MANAGEMENT
AUTHORITY

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QUICK REFERENCE GUIDE

FOREWORD from the Governor of Victoria

Natural Values: Exploring Options for Enhancing Ecosystem Services in the Goulburn Broken Catchment is the culmination of four years work and the first of its kind in Australia. It began with a vision; to reconnect Australians with the environment that surrounds them and supports their life choices. In essence to change the way people view the environment, not as a resource to be taken for granted but one to be valued for the free services it provides and one worth investing in. Whilst it was always an ambitious goal the project has made tremendous progress in promoting the concept and contributing to the science.

The Myer Foundation, as part of the Sidney Myer Centenary Celebration, acted as a catalyst to initiate the project, strengthening the growing role of philanthropic organisations in promoting science not ordinarily funded through traditional sources. This association has proved very successful and facilitated the brokerage of further funding from Land and Water Australia for the case studies conducted in the Goulburn Broken Catchment and presented in this report, along with several sister projects.

The Goulburn Broken Catchment Management Authority (GBCMA) was quick to recognise the benefits that the ecosystem services approach could provide its members and the community as a whole. Already in the process of drafting their Catchment Management plan, they formed a strong and lasting relationship with the research team. This partnership between scientist and client, each learning from the other, brought out possibilities not before considered, guided the research effort and provided the GBCMA with a framework to achieve resource management targets. Their enthusiasm and dedication to the project has been invaluable, without their input this exceptional piece of science would not have been possible.

Natural Values builds on the outcomes of the inventory report *Natural Assets: An Inventory of Ecosystem Goods and Services in the Goulburn Broken Catchment*, which I was pleased to launch in Shepparton in 2001. This publication, the first product from the project, identified key industries that would benefit from the preservation and investment in nature's services, laying the foundations for much of the following work.

This second report presents the findings, recommendations and achievements of The Ecosystem Services Project in the Goulburn Broken Catchment. It documents theories and methods for assessing a variety of values attributable to ecosystem services under likely scenarios of catchment management in the Goulburn Broken. It discusses the implications of the results and methods in terms of catchment management, policy formulation and application of research.

Anyone involved in resource management or in the policies that guide the use of our natural capital should read and consider the recommendations of this report.

John Landy, AC, MBE
Governor of Victoria

FOREWORD
from our collaborators in the Goulburn Broken Catchment

The Ecosystem Services project has had an immense impact on the Goulburn Broken CMA and its partners, including the catchment community. It has opened our minds to new concepts and helped our thinking on the best ways to protect and enhance the Catchment's valuable natural assets and the services they provide.

The concept of Ecosystem Services has become an integral part of what we do at both the strategic level, (evident in the recent renewal of our Regional Catchment Strategy) and also at the operational level.

Indeed, our vision is very clear about the importance placed on Ecosystem Services in the Goulburn Broken catchment: "…The environmental footprint of irrigation and dryland farming will be significantly reduced, with farmers occupying less land and using less water whilst managing their water more sustainably. New opportunities will arise for increasing ecosystem services provided by the land retired from agriculture and by improved environmental flows".

The project has involved a wide range of stakeholders in the Catchment. The many workshops and events that informed the project provided an opportunity for people to exercise their minds, think about new concepts and look positively to the future.

The case studies have been useful in developing tools to aid decision-making. They have also helped demonstrate the range of values provided by floodplains and highlighted the range of benefits offered by landscape planning.

CSIRO has taken a brave step in the right direction with its willingness to start interpreting and presenting best available science in a form that will aid decision/policy making. It is part of a promising trend that is seeing researchers building closer links with the people involved in environmental management in a hands on way.

I hope you will take the time to read this report that is a wonderful addition to the thinking, planning and implementation of natural resource management policy in the catchment.

Bill O'Kane
CEO
Goulburn Broken Catchment Management Authority

FOREWORD
from the Chair of the Management Advisory Board

This report marks the end of the first phase in a program to understand and promulgate the nature and importance of ecosystem services in Australia. It had a rocky start, being considered initially by the relevant research agencies as too vague or too risky. Only after substantial support from the Myer Foundation did it get going and from there it has never looked back.

At the very first meeting of the Management Board the importance of communication was emphasized and a significant proportion of the budget was chanelled into this. It has been a difficult task, balancing the allocation of limited funds between a very big demand for basic research and the need to educate resource managers, bureacrats, politicans, scientists and the public. I think the whole team has reason to feel satisfied that they have done an excellent job. The notion of ecosystem services has risen markedly on the agendas of many agencies. It has become known in the media, and has taken hold.

The research team wishes that it could have done more field work, but in my view they have provided a solid base given the resources they had, and this report lays the foundation for continued work. It is my hope that the next phase will not be just another 3 or 5 year funded project but, rather, an on-going national program with many such projects. A new initiative in markets for ecosystem services is underway. The challenge is to establish a way to maintain co-ordination between all the new projects that will emerge, so as to derive the benefits from the synergies that will flow from a collaborative program.

I commend this report to all those interested in achieving sustainable development in natural resource use. I thank my fellow Board members for their guidance and support for the project, and I congratulate the research team on a fine product.

Brian Walker
Chair
Management Board of the Ecosystem Services Project

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ACKNOWLEDGEMENTS

The project was funded by The Myer Foundation at a time when the ecosystem services concept was new to Australia and could not attract support from other major sources. The belief of Lindy Hayward, Charles Lane and others in The Myer Foundation in the importance of the concept has been borne out by the major emphasis now placed on ecosystem services in environmental and natural resource management policies. Land and Water Australia were also early supporters and funders and we thank Andrew Campbell, Chief Executive Officer, for the involvement of himself and his organisation throughout the project, including his valuable service on the Management Advisory Board. This project was conceived by Brian Walker, who subsequently became the chair of our Management Advisory Board. We thank him for his many contributions during the project, including authorship of one of the sections in this report. We thank the other board members: Michael Baevski, Samantha Bailleau, Andrew Cambell, Marc Carter, Rhonda Dickson, Lindy Hayward, Stephen Hunter, Phil Price, Peter Thomas and Bernie Wonder.

The work reported here is the result of a partnership between the Goulburn Broken Catchment Management Authority and CSIRO Sustainable Ecosystems. Bill O'Kane, Chief Executive Officer, John Dainton, Chair, his successor Steve Mills and Kate Bell, Biodiversity Manager have worked closely with us throughout the project and we thank them for their advice and insights. Our Steering Committee, chaired by Dianne McPherson with Terry Bailey, Neil Byron, Rob Floyd, Charles Lane, Pat O'Connor, Bill O'Kane, Kevin Ritchie and Mike Young, has provided valuable feedback during the project and on our final report. Kate Bell, Steve Hatfield Dodds, Allen Kearns, Denis Saunders and Mike Young are among those who reviewed our final report and suggested many changes that improved the document substantially.

We thank Carl Binning who was a key member of the research team until his secondment to Greening Australia in 2001, and lead author of our first publication (Natural Assets).

Some of the many individuals who have contributed to this work include:

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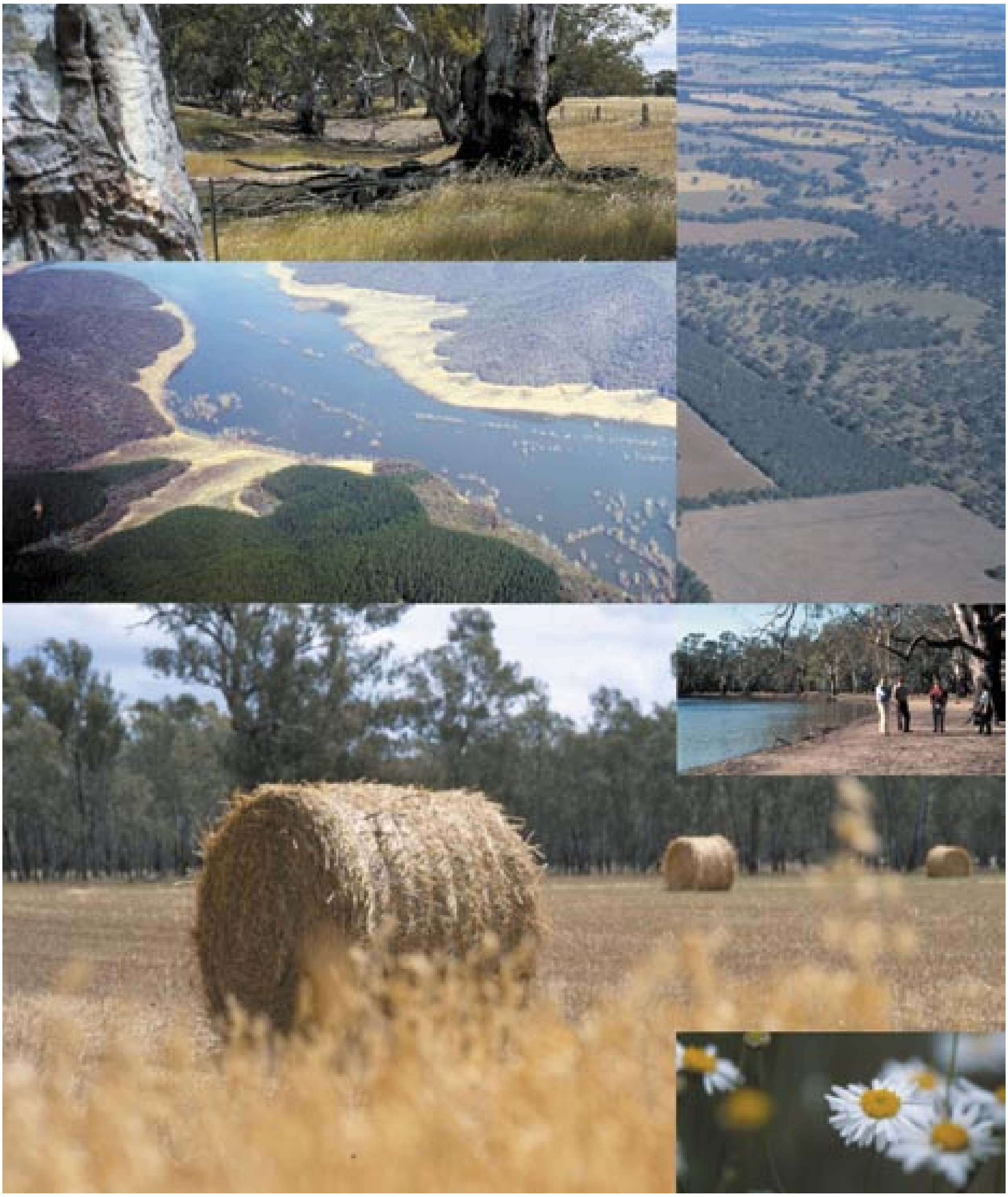
Our deepest thanks to all.

EXECUTIVE SUMMARY



EXECUTIVE SUMMARY

This report summarises results of the first ecosystem services project undertaken in Australia. The project has sought to introduce a new way of thinking about the relationship between people and the environment they depend on.

Ecosystem Services are "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life" (Daily 1997). They include: inputs to production; regeneration of ecosystems; stabilisation of soils, climates and weather; assimilation of wastes; amenity; and options for the future. Although sustainable human well-being depends on ecosystems, humans degrade them. The ecosystem services concept confronts this paradox.

Origin, aims and scope of this research

In 1998 a proposal for research on ecosystem services was judged by various agencies and the CSIRO to be too risky, too ill-defined or too unscientific to justify investment. The Myer Foundation decided that the concept could be important for Australia and deserved testing. Their support gave credibility to the research, and two projects were developed. "The Nature and Value of Australian Ecosystem Services", was a research and communication network funded jointly with CSIRO. The other, "Assessing Ecosystem Services in the Goulburn Broken Catchment" applied the ecosystem services concept in the Goulburn Broken catchment of Victoria. The Myer Foundation, CSIRO, the Goulburn Broken Catchment Management Authority and Land and Water Australia supported it. This report focuses on the Goulburn Broken work, but because the staff and communication activities of the projects over-lapped, we also report on the outcomes of the research and communication network project. This has arguably had a key role in changing the way Australian policy makers, researchers and communities think about natural resource management.

The aims of the Goulburn Broken project were to:

- estimate the benefits of ecosystem services at a range of spatial and temporal scales as a way to help policy makers, planners and land and water managers take account of the inter-relationships among a range of ecological, economic and social values;
- work with policy makers, planners, land managers, industry and community groups to raise awareness of the values of maintaining ecosystem function;
- recommend policies and practices that maintain these values; and
- communicate project results widely.

Implicit aims were to evaluate the concept, and to develop and test methods.

The main elements of our approach to assessing ecosystem services were: the engagement of stakeholders in participative research; an inventory process to focus on sets of ecosystem services and select case studies across a range of scales; the development of scenarios; and analytical methods and models for assessing ecosystem services. The research was based on five case studies within the Goulburn Broken Catchment.

Economy and land use in the Goulburn Broken Catchment

The Goulburn Broken catchment covers 2.4 million hectares. It extends from the mountains of the Great Dividing Range, to the riverine plains of the Goulburn and Broken Rivers. The combined mean annual flow of its rivers is approximately 3,300 giga-litres, of which about half is extracted for irrigation and urban consumption. Extensive clearing of native vegetation has resulted in salinisation and deteriorating water quality and soil health. Land use is dominated by agriculture, with dryland agriculture covering more than 1,300,000 hectares and intensive irrigated agriculture, particularly for dairy and horticulture, accounting for approximately 300,000 hectares. Tourism and recreation are emerging as an important land uses. The human population of the catchment is currently 190,000 and increasing. Commodities from the catchment form a significant proportion of the agricultural exports from Victoria. Total gross dollar value of production from the catchment in 2001 was $ 8,709 M, and is predicted to grow. Like all regional communities, the Goulburn Broken faces numerous challenges in balancing the need to maintain economically and socially viable rural communities while simultaneously meeting the expectations of the wider community to manage natural resources sustainably and with minimal down stream impacts.

Development and the depletion of natural capital

Development is the improvement of economic, social, cultural and environmental well-being of people (Coombs 2001). To achieve it, economic and social capitals are applied to extract value from natural capital. Economic capital is the physical means of production and distribution. Social capital includes knowledge and skills, plus the social arrangements for production and distribution, and for monitoring, taxing, regulating, encouraging and punishing individuals. Natural capital is embodied in ecosystems, and it supplies numerous goods, such as timber, as well as ecosystem services. Natural capital can be self-sustaining, but can also be irreversibly damaged. Although many of the ecosystem services it provides are not substitutable with technological alternatives, as economic and social capitals have grown in the Goulburn Broken catchment, natural capital has been allowed to decline to levels where the benefits of development are less than they could be, and future well-being is threatened.

The production and valuation of ecosystem services

Valuation of ecosystem services is necessary if markets and institutions are to be established to promote the sustainable and efficient use of ecosystem services. One of the key assumptions of economic valuation is that consumers and producers have perfect knowledge about what they are paying for. However, this knowledge is not available for many important ecosystem services or the processes that underpin them. Given the complexity of the ecosystem processes and our general ignorance about them, our priority in this project was the biophysical basis of value, not the estimation of dollar values. In the language of economics, we built "production functions" for ecosystem services. A production function is the quantitative relationship among a set of physical inputs, human knowledge, skills and labour, technology and the physical quantity of an output. This is fundamental to estimating value, and to understanding the degree to which other forms of capital can replace natural capital.

Communication and participative research

A network of policy makers and researchers was established by "The Nature and Value of Australian Ecosystem Services" project. It includes scientists working on ecosystem services in rangelands, rainforest and irrigated cotton. Our participative research approach in the Goulburn Broken Catchment was designed to link local and scientific knowledge, and channel research towards priorities in the catchment through an inventory process and subsequent workshops based on the five case studies.

Which services matter

Studying every ecosystem service is impossible so we used a participatory inventory process to select services important to the catchment community. Working with stakeholders we identified the main products from the catchment that people value. The ecosystem services supporting their production were also identified and ranked in terms of the revenue the products earn, the impact on production of a small change in the service, and the capacity of the industry producing the product to ensure the sustainability of the service. Five case studies focusing on selected services were chosen. The services considered in the case studies are: life-fulfilment; regulation of climate; maintenance and regeneration of habitat; provision of shade and shelter; maintenance of soil health; maintaining healthy waterways; water filtration and erosion control; and regulation of river flows and groundwater levels.

The case studies

The five case studies were selected to represent a range of spatial scales and ecological processes. Our study of a dairy enterprise is based on a non-spatial dynamic model. Our landscape study is an assessment of ecosystem services on a floodplain. It is based on a dynamic model that includes spatial variation. The next case study is an analysis of ecosystem services in a dryland sub-catchment. It is based on a spatial analysis of native vegetation patterns 'grown' in a geographical information system according to rules drawn from conservation policy. We evaluated the effects of these patterns on a range of important ecosystem services. Our study of tourism and recreation is at a sub-regional scale. It used a stakeholder process, expert knowledge and multi-criteria evaluation, and tracked changes in participants' understanding of ecosystem services. At the scale of the whole Goulburn Broken Catchment we used input-output modelling to relate water inputs to employment levels, and the outputs of dollar 'values' and nutrients. Details of each case study are in Sections 7 to 11. Achievements, findings, recommendations and future work arising from this project are summarised in the next two sections.

Achievments, findings and recommendations

The ecosystem services concept is now in the vocabulary of agencies, land managers and politicians

Our communication has been highly effective. The ecosystem service concept has entered the vocabulary of agencies, land managers and politicians and is being used in plans and policies at local, state and federal levels. The term appears in major state and Commonwealth environmental policy and discussion papers. The Bureau of Rural Sciences is establishing an ecosystem services unit to assess services at national scale. The New South Wales Environmental Services Scheme is operating at 27 sites across the State. A new $5 million 'Market-based Instruments' initiative has been launched by the Federal government to test a variety of mechanisms for sustainable use of ecosystem services. Ten pilot projects are located in Queensland, New South Wales, Victoria, South Australia and Western Australia. At least ten other ecosystem services projects have been proposed or have started. We cannot claim these would not have happened without our project, but we are confident our communication activities have helped create a policy, funding and intellectual environment in which ecosystem services projects are treated much more favourably than they would have been in 1998. Ecosystem services is a central theme in the Goulburn Broken Regional Catchment Strategy, agencies are introducing the concept to landholders, and it is used by other Catchment Management Authorities/ Boards.

We have built a national and international research network

We have built links with ecosystem services researchers in Australia, New Zealand, the US, Germany, Switzerland and South Africa, held scientific workshops, hosted two Ecosystem Services symposia, and developed links with other CSIRO divisions and a range of agencies and consulting firms. We have given conference papers or attended workshops on every continent except Antarctica. Almost 1500 copies of *Natural Assets: An Inventory of Ecosystem Goods and Services in the Goulburn Broken Catchment* (Binning and others 2001) have been distributed.

The ecosystem services website is spreading awareness of ecosystem services among the broader community

Our research network and communication strategy has promoted the sharing of knowledge about the value of Australian environments among researchers and other members of society through newsletters, leaflets, papers and presentations to state and Commonwealth natural resource management agencies, at public meetings in catchments, and at conferences. The new project website (http://www.ecosystemservicesproject.org/) is a major avenue for communication, and an electronic newsletter is distributed by email.

The ecosystem services concept provides a framework for integrating research across disciplines and among policy makers, stakeholders and researchers

The ecosystem services concept enables local and scientific knowledge to interact to their mutual enhancement. In addition to this exchange of ideas, local knowledge guides researchers towards work that has practical use. The concept also brings disciplines together under a common theme to facilitate better interaction among scientists.

Participatory research enhances the sharing of ideas and knowledge about ecosystem services

Participatory research enabled researchers to identify key issues that policy makers and land managers face, and to adapt the concept of ecosystem services to these issues. Through participation, the concept has become known in the major organisations in the Goulburn Broken catchment and regional environmental and primary industries agencies. These agencies have further adapted the concept for their purposes.

A participative process guides the direction and scope of the research and enhances learning

Scientific and local knowledge were exchanged, modified and combined through participatory research. The direction and scope of the project were guided through this exchange. The deliberative process used in the tourism and recreation case study is a model for further participative research.

Understanding about, and willingness to act on, the values of ecosystems appears to be increasing among land managers and policy makers

While the concept of ecosystem services is useful in increasing understanding of environmental issues and channelling dialogue towards solutions, it is only one progressive force among many. People and organisations in the Goulburn Broken catchment have a long history of re-conceptualising environmental challenges in ways that involve the public in solutions, and our project rode, to some extent, on the back of those earlier initiatives. Ecosystem Service projects currently running in other catchments will provide a comparison of the approach in catchments where the community is less proactive.

Generating stakeholder enthusiasm to value ecosystem services needs to be balanced against the capacity of researchers to estimate those values

Our communication effort, which raised enthusiasm among a range of partners and researchers, moved faster than our research effort, and some unrealistic expectations were raised. We have learned the importance of managing expectations among stakeholders and researchers, and how to do it. For example limiting the research to the five component case studies, has proven to be both feasible and useful.

It will take much more than changes in attitudes to achieve sustainability

There is an expectation of the ecosystem services concept that it will lead to national and regional sustainability through changes in attitudes. It is not so easy. Reversing ecosystem degradation will require changes in the distributions of benefits and costs within and across generations. We expect the concept of ecosystem services to play an informing role in this process, helping stakeholders to understand their relationships with nature, but to achieve sustainability people must also change their relationships with each other through institutional reforms, and deliver their obligations to future generations.

Research partnerships need trust

Project partners began to build mutual trust from the beginning of the project. We began with a workshop in which expectations of all parties were explored and documented. It was reinforced by a Relationship Agreement and by equal representation and shared authority on the project Steering Committee. During the project there were changes in key staff in the research team and CMA. There were also major changes in political and financial pressures for all partners. It is a particularly important aspect of this project that these pressures did not undermine trust in the relationship and that all partners remained committed.

Ecosystem services need to be carefully defined

Ecosystem services were defined by stakeholders during our participative process to ensure the relevance of the services to their goals, and to ensure the services are communicated in a way that is understood by the community. However, multiple stakeholders reinterpret the intended meanings, so original definitions can come to mean different things. A description of the service and its context and purpose is needed to ensure the original meaning is retained and conveyed to researchers and others.

There is a range of ways to express ecological, economic and social values

This report focussed on the production and roles of ecosystem services, rather than users' perceptions of their values, so it was appropriate to represent ecological, economic and social values using different units, rather than lose information by expressing them as a single unit. The dryland catchment study used biophysical units. In the dairy and floodplain studies we brought ecosystem services and outputs such as soil and nutrient losses expressed in biophysical units together with gross margins in dollars. The evaluation of recreation and tourism in the upper Goulburn Broken Catchment showed how a deliberative process linked with multi-criteria evaluation can be used to quantitatively integrate values expressed in different terms and units. In the whole-of-catchment input-output analysis our units were numbers of people employed as a measure of social value, mega-litres of water as a measure of the ecosystem service input, sector outputs in dollars and tonnes of nitrogen and phosphorus as negative impacts on ecosystems.

The dairy case study illustrates the dependence of high intensity enterprises on ecosystem services provided from a broader scale

The dairy case study has identified the need for better understanding of the contributions of soil organisms and native predators to pasture production. It reinforced the need for more effective ways of capturing and recycling nutrients because of their negative impacts on other ecosystem services. It also showed the relatively low priority of on-farm ecosystem services. At a broader scale dairy farms could not continue to function if the external ecosystem services fail. The dairy industry is a source of much of the region's income so there is a strong economic argument for investing in natural capital at the broader scale.

The inclusion of ecosystem services may increase the net social benefit of changing management regimes

Ecosystem services not included in the floodplain benefit-cost analysis may represent a significant increase in the net social benefit of the proposed change in flood management. Our sub-catchment case study illustrates a related point — the ecosystem services provided by the sub-catchment under a different vegetation cover may be more valuable to the whole catchment than the value of the current agricultural outputs. This points to the potential of markets or other incentives through which land holders produce ecosystem services that support the functioning of the Goulburn Broken catchment as a whole.

Enhancement or maintenance of ecosystem services requires a priority setting process

The 'Inventory' approach to setting research priorities was appropriate for a participatory research project in which local knowledge and values guided priorities and played a central role in setting the research agenda. An extension to the Inventory approach is one based on functional roles of ecosystem services, and the biophysical processes that underpin them.

A hierarchical framework of interactions between services helps setting priorities

Ecosystem services can be grouped within an hierarchical framework according to their functional relationships and relative influences. The grouping enables services to be prioritised for research or management. Our implementation of this prioritisation framework applies to this catchment only, but the method can be generalised.

Scenarios enabled structured comparisons of options

To explore potential changes in ecosystem service outputs in a structured way we established scenarios in consultation with stakeholders. With the exception of the dairy enterprise, in each case study one scenario reflected current conditions as a baseline to compare with other scenarios. The other scenarios were chosen to represent desirable or undesirable alternatives, or alternatives reflecting different stakeholder groups or policies. The output of ecosystem services was then evaluated by comparing scenarios. We adapted this general approach to suit the context of each case study, but in each case stakeholder's participation ensured our scenarios were related to the priorities of managers, the Catchment Management Authority or state policy.

Interactions among variables in our case studies meant that responses of services to changes in land use or management were often unpredictable. The scenario approach enabled us to explore uncertainties as well as beneficial and unwanted thresholds. These have major implications for policy and implementation.

Better production functions are needed to evaluate the benefits and costs of changes in ecosystem services

A production function is the quantitative relationship among a set of physical inputs, human knowledge, skills and labour, technology and the physical quantity of an output. An ideal production function for ecosystem services should be able to model variation in time and space. These and other ideal criteria are discussed below. In practice simplification is necessary, and we adapted a variety of approaches to build production functions for the case studies. Evaluation of the dairy and floodplain case studies were based on dynamic simulation models with integrated evaluation of ecosystem service outputs. Dynamic models confer the ability to explore easily the effects of small changes in management and land use, and interactions among services can be captured well, but the capacity to explore spatial relationships is limited. Spatial capability was strong in the dryland sub-catchment case study, but the wide range of services evaluated led us to rely on a set of separate analytical techniques and models for evaluating the services separately. Given this lack of integration, interactions among services could not be evaluated comprehensively. Evaluation in the recreation and tourism case study was by expert knowledge. The ability to estimate changes in ecosystem services over time and space, and interactions among services, depended on the knowledge and human limitations of the experts. Evaluation in the input–output analysis of the Goulburn Broken Catchment was limited to water inputs and nutrient outputs by the simplicity of the model, but water and nutrients were well integrated with the structure and outputs of the economy.

Requirements of ecological-economic production functions

Production functions provide the fundamental link between ecology and economics. Ideal ecological economic production functions would:

- be calibrated against empirical data;
- be validated against independent empirical data or expert knowledge;
- deal with time;
- deal with space;
- incorporate industrial and ecosystem inputs;
- estimate the impact of current production on future production;
- estimate externalities; and
- be able to represent non-linearity.

It will not necessarily be worthwhile to build comprehensive production functions satisfying all these criteria within the one model. In most cases a set of partial analyses may be more cost-effective. The choice of models and analytical methods should be driven by the purpose and context of the analysis, more detail is not always better, and much useful work can be done with simple models and analyses.

Combining citizens' jury and multi-criteria evaluation is a powerful way to capture and develop community values

The Deliberative Multi-criteria Evaluation developed in this study provided a powerful means by which stakeholder values can be captured and complex decision problems broken down into more manageable pieces. The Citizens' Jury process enabled several decision-makers to express their priorities, debate their positions and learn more about the decision problem by calling on expert knowledge. The Jury process combined well with Multi-criteria Evaluation, which allowed for the unravelling of complex decision problems and the identification of trade-offs. The development of an impact matrix through expert input meant that decisions could be made regardless of the availability of formal information.

Complex research projects are likely to miss deadlines

The extensive gaps we found in theory, methods and data coupled with the complexity of the interactions in the systems we studied meant that some delays were experienced in producing the analyses expected by our stakeholders. The breadth of our analyses made us dependent on data generated by models that other researchers were developing, and as their timelines slipped, so did ours. Lacking input data, our floodplain model is still not operational, and is a demonstration of a concept, not proof of it.

Impediments to data sharing provide a significant barrier to understanding complex social-ecological systems

One impediment to data sharing is the absence of a standard data license agreement accepted by Federal and State Governments. Presently data licenses are created by individual organisations and vary in restrictions on data use and ownership of data generated by the user. Another impediment is the move of many Federal and State organisations to claim intellectual property in data sets created by their publicly funded organisation. The resulting data costs to the user in unnecessary and impedes research.

Investment to increase understanding of biophysical processes is a necessary foundation for better management of ecosystem services

Many policy makers and funders believe that most degradational processes are scientifically well understood, and that implementation should proceed without further investment in research. However, the development of incentive or regulatory schemes, or markets for ecosystem services, even at a pilot level, needs reliable estimates of responses of ecosystem services to changes in vegetation cover or management. Participants, including governments, cannot be expected to commit resources when uncertainty is high. Schemes that proceed and fail through lack of biophysical understanding will discredit approaches that would have worked if knowledge had been sufficient. In our research we found large gaps in knowledge that often left us unable to calibrate and validate models and analyses. Where stakeholders identified a priority ecosystem service that is produced by ecosystem processes that are poorly understood, there is a strong case for investing in basic research. The many knowledge gaps we identified show there is a lot of that to be done. While the priorities will be different in other Australian catchments, the social and environmental returns to investment in research could be high if prioritisation followed the inventory and functional approaches we developed.

New incentives, regulations or markets are needed to protect ecosystem services that are over-exploited or under-managed

Policies should be focused upon ecosystem services that are vulnerable because they have not been captured by private or common property (group) rights, so that benefits and responsibilities are not attributed to an individual or group. These open access services are usually without clear biophysical boundaries, or with boundaries that do not match farm, forestry or conservation area boundaries. New institutional arrangements may promote their sustainable use. These could be regulatory, incentive or market-based. An example is clean water from agricultural sub-catchments provided by the service "water filtration and erosion control". This service is dispersed across the properties in the catchments, and agreements among farmers would be needed in order to realise the benefits of managing the whole catchment to improve water quality. Water users could make payments for the provision of the service. Used in combination with the prioritisation framework outlined earlier, a property rights approach can focus policy and research effort on services that are both functionally important and vulnerable.

The tourism and recreation case study identified particular policy needs for maintaining ecosystem services that support that sector

Through the workshop process the case study highlighted the need for greater research on public access issues, the effects of education on tourists and environmental damage, methods for the recovery of management costs and the role of market and other incentives in limiting environmental damage of recreation and tourism activities.

The sub-catchment case study shows where investment in native vegetation is worthwhile

We drew on State and catchment guidelines for conservation of biodiversity and applied them to the current landscape in a geographical information system (GIS) to drive the pattern of revegetation in the dryland sub-catchment case study. However, investment priorities could be determined for any future time period if the input data are updated to reflect on-ground plantings inside or outside the sub-catchment. Running the GIS to achieve an increase in the target identifies the next set of sites for priority planting. The rules and their weightings can be changed as new information is acquired from the sub-catchment or outside. The approach could also be applied at a broader scale, with different rules and weightings in different zones.

A native vegetation target of 15% produces only small increases in ecosystem services

Modelling of revegetation in Sheep Pen Creek suggests that an increase from the current level of 8% of native vegetation to a 15% target produces only small increases in ecosystem services as indicated by habitat configuration scores, carbon storage, shelter, shade, stream sediment load, sheet and rill erosion control, deep drainage control and control of soil acidity.

The response of ecosystem services to landscape changes may have thresholds that indicate where efficient revegetation targets should be set

Our analysis of Sheep Pen Creek shows thresholds in the relationship between area under native vegetation and the estimated value of native vegetation as habitat for native biota. The thresholds suggest that initial investment to increase the current cover to a 10% target give a good return per hectare revegetated, but the rate of return declines thereafter, increasing again after another threshold is crossed above the 30% target.

Policies aimed at restructuring the regional economy could increase the efficiency of water use without necessarily reducing jobs or gross regional product

The input-output analysis of the economy, water use and nutrient outputs illustrates which sectors could be targeted by regional development policies in order to restructure the economy to achieve more efficient use of water in the generation of dollar outputs or jobs. It can also examine, within the limitations of the data, economic structures that reduce pollution. The approach we developed is an effective way of engaging industry groups and state policy makers in exploring the possibilities of alternative economic structures and ways of achieving them.

Increased understanding of ecosystem function at different scales can improve the cost-effectiveness of investments in natural capital

In the past, vegetation patterns in catchments have been determined by property-scale decisions of farmers. The resulting vegetation patterns are inefficient for regulating salinity or conserving biodiversity, because many of the biophysical processes do not operate at property scale. To achieve efficient salinity control and biodiversity conservation, vegetation patterns and the policies that influence them need to be determined at sub-catchment scale or broader.

The Goulburn Broken Catchment is already pioneering ways of investing in natural capital, and the ecosystem services concept contributes to their strategic investment planning. From our case studies at enterprise, landscape, sub-catchment, regional and whole-of-catchment scales we can estimate the effectiveness of investment in natural capital at each scale, and consider the form of natural capital to invest in (e.g. commercial forestry or native vegetation). However, an investment in natural capital at one scale affects processes at other scales too. Our preliminary quantification of flows of ecosystem services at selected scales can contribute to a plan for strategic investment in natural capital that takes explicit account of scale effects. It enables better prioritisation of resource degradation issues, and replaces arbitrary targets for remediation, such as percentage tree cover, with process-based spatial layouts. The suite of models and analytical approaches we developed illustrates the strategic potential of a cross-scale approach.

Policies and practices for maintaining or enhancing ecosystem services

A set of policies and practices to maintain or enhance ecosystem services arises from our case study findings. Some can be generalised, others are specific to the Goulburn Broken Catchment. They are listed below.

Dairy enterprise

Strengthen policies (e.g. water markets, water property rights, water quality monitoring and regulation, tradable pollution permits) that promote water re-use and nutrient retention on farm.

Strengthen or establish policies (e.g. offset schemes) that promote establishment of native vegetation on outblocks (or elsewhere) to compensate for greenhouse gas emissions from, and lack of habitat for native species, on the milking areas.

Invest in research on soils and soil organisms under intensive irrigation and fertiliser regimes. Are there long term trends or critical thresholds? What are the limits of intensification? Can irreversible changes occur? Is the balance of soil ecosystem services to industrial inputs financially efficient and sustainable?

Invest in research on natural pest control in pastures.

Floodplain

Develop recommendations for floodplain policies and practices.

Invest in an adaptive management research program on regeneration of native vegetation under different flood regimes, the evolution of Habitat Hectares scores, and the interventions required to achieve benchmark structure and species composition

Invest in research on the filtration of water by floodplain vegetation

Dryland sub-catchment

Increase native re-vegetation targets to take advantage of thresholds in ecosystem service responses e.g. above 30% of the area re-vegetated for Habitat Configuration score, and around 40% for shelter.

Given these thresholds, investments should be focused, not spread across the Goulburn Broken Catchment.

Link incentives for re-vegetation to sub-catchment plans so that efficient trade-offs are made among the ecosystem services 'maintenance and regeneration of habitat', 'provision of shade and shelter', 'water filtration and erosion control', 'maintaining healthy waterways', and 'regulation of groundwater and river flows'. These services are more-or-less sensitive to the spatial arrangements of the vegetation.

Design incentives for native re-vegetation so they promote re-planting of species appropriate to the Ecological Vegetation Class (EVC) in which each site lies, on sites:

- that are geographically dispersed in order to reduce risks;
- in areas where where the soils are locally variable — this increases the range of habitat possibilities in a given area;
- in EVCs that are rare in the bioregion, so that representation of these EVCs is increased;
- where rare and threatened species occur in order to enhance their survival;
- near existing remnants that have a higher canopy density. This builds connections among remnants in which the higher canopy density indicates better habitat for native biota;
- in areas where patches of remnant vegetation are already numerous. The habitat value of the planted site is enhanced by the adjacency of the remnants;
- near larger existing remnants. The habitat value of the planted site is enhanced by the size of the remnant;
- near streams as these provide good habitat for native fauna and several other ecosystem services;
- that are enclosed by native vegetation. This enables small remnants to coalesce into a large patch with a higher overall habitat value;

- that make short links between remnants as fauna using short corridors may be less vulnerable to predation; and
- far from productive agricultural land to reduce the risks from intensive management practices.

Invest in an adaptive management research program on regeneration of native vegetation, the evolution of Habitat Hectares scores, and the interventions required to achieve benchmark structures and species compositions.

Tourism and recreation

Adopt deliberative processes combined with multi criteria evaluation in the development of other sub-strategies and plans for the Goulburn Broken Catchment

Invest in research on :

- public access;
- public education and the maintenance of ecosystem services;
- an efficient set of measures for reducing damage to or enhancing ecosystem services (e.g. user pays, markets and regulations);
- the utility of a code of practice for operators for reducing damage to ecosystem services; and
- the scope for reducing the number of or coordinating the many agencies involved in managing ecosystem services in the upper Goulburn Catchment.

Water inputs and nutrient outputs from the Goulburn Broken economy

Create regional development policies that take account of the sectoral output, employment, water and nutrient multipliers and promote economic restructuring.

Future Work

A high priority for future work is to analyse the institutions needed to maintain ecosystem services, and in particular explore ways of matching the scale and the design of institutions to the scale and nature of the ecosystem processes they are intended to influence. Another priority is to explore the feasibility of markets for ecosystem services, including the supporting institutions. We launched a new project in 2002, which is an attempt to redress market and property right failures and encourage investment in natural capital (http://www.ecosystemservicesproject.org/html/markets/aboutus/index.htm). It is funded by CSIRO, the Rural Industries Research and Development Corporation, Land and Water Australia, the Goulburn Broken CMA, NSW Department of Sustainable Natural Resources, Colleambally Irrigation, the Blackwood Basin Group, and the National Market Based Instruments Program. A supporting project on experimental economics funded by CSIRO will explore the decision-making behaviour of resource users under controlled conditions.

Another proposed ecosystem services project is called "Putting Ecosystems to Work for Town Water Supply", this project would draw upon the experiences of the Ecosystem Services Project and the Markets for Ecosystem Services Project in making use of natural capital to provide clean water to towns through ecosystem services markets in rural catchments. We predict a spread of similar projects as the costs of providing clean water increase in Australia and globally.

Concluding Remarks

The ecosystem services concept is rapidly influencing the way stakeholders perceive the relationships between natural capital and development, and is encouraging investment in natural capital, markets for ecosystem services, and in related research and communication.

If humans perceive themselves as separate from nature it then follows that development has no environmental cost. The contradiction of historical development is that it has caused the degradation of natural capital even though human well-being and survival depend on the services provided by that capital. The ecosystem services concept places humans and their economies within ecosystems so that 'natural' and economic processes are intimately interconnected. It is a step towards the integration of ecology and economics. It shows the need for investment in the maintenance of natural capital because it is the primary source of value and the provider of life support. This idea is obvious, but the reluctance of societies to bear the costs of maintaining natural capital shows the need for frequent restatement and reinforcement of the idea. The ecosystem services concept changes the need for investment in natural capital from an option to an imperative.

The Goulburn Broken Catchment Management Authority is already pioneering ways of investing in natural capital, and the ecosystem services concept contributes to this investment. We have shown how quantification of ecosystem services at selected scales (case studies) contributes directly to catchment planning. The awareness of transfer of services across scales can contribute to investment in natural capital that takes explicit account of otherwise unrecognised scale effects.

Within the framework of ecosystem services there is a range of ways to integrate ecological, economic and social values. The choice and definition of the services, an inherently social process, is critical to their understanding. They define the set of biophysical processes that underpin the ecosystem services, processes that lead to interactions between services and provide the indicators for the relative performance of each service. However, the processes are often poorly understood and greater investment to link process with service is required to ensure the ecosystem services concept reaches its full potential. Analysis can vary in scale from enterprise to catchment and can utilise tools from dynamic modelling to multi-criteria evaluation. All should be linked with participatory methods that connect researchers and community together. This increase in understanding of ecosystem processes is fundamental to the establishment of markets for ecosystem services, and for political acceptance of the need for other changes in institutions for natural resource management.

To take the concept of ecosystem services further we need to build on three themes introduced in this project. First, production functions that recognise spatial, temporal and feedback processes and provide the necessary link between ecology and economy. Second, it is unlikely there will be sufficient investment in environmental management to match the extent of degradation. There is therefore a strong need for priority setting tools that can guide society's investment in the management of ecosystem services. The nested hierarchy framework presented in this report is one process for setting priorities. Lastly because many ecosystem services are not readily captured and managed within private or group property rights institutions, there is a need for new institutions that will protect the value of these services.

1 Origin, aims and scope of this research

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"Ecosystem Services" are "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life" (Daily 1997). They include (de Groot and others 2002):

- inputs to production;
- regeneration of ecosystems;
- stabilisation of soils, climates and weather;
- assimilation of wastes;
- amenity; and
- options for the future.

Use of the concept by researchers and environmentalists has increased since the 1970s in attempts to reverse the degradation of ecosystems by bringing the attention of people to their dependence upon those systems (Holdren and Ehrlich 1974; Westman 1977; Ehrlich and Ehlich 1981; Daily 1997; Costanza and others 1997; Cork and Shelton 2000; Cork and others 2001; Daily and Ellison 2002). The concept makes human well-being and survival central themes. While human-centredness is unacceptable to some philosophies (Drengson and Yuichi 1995), it does represent the way most people think. It thus gives important insights into the kinds of information and institutions that would encourage people to maintain ecosystems.

People degrade ecosystems for several reasons (Pearce and Warford 1993). They may be ignorant of the benefits flowing from ecosystems, or of the impacts of use. Often the flow of benefits from a resource and responsibility for its management have not been allocated to an individual or group, so it is over-exploited or under-managed. A related cause is that no markets exist for many ecosystem outputs, so the resource is not valued and is therefore neglected. Often markets do not reflect the full costs of production, so environmental damage is not treated as a cost. In other cases a tax or subsidy intended for some other purpose encourages overuse. It also happens that a government agency takes on a physical planning role that causes degradation. Sometimes degradation

Figure 1.1 Locations of projects linked to "The Nature and Value of Ecosystem Services"

occurs because the human population increases and over-consumes the resource. In other cases poverty drives some resource users to mismanage their land knowingly. Finally, people may knowingly over-exploit resources in their own short-term interests.

In 1998 interest in applying the concept to Australia's growing environmental problems was small. A proposal for research on ecosystem services was judged by various agencies and the CSIRO to be too risky, too ill-defined or too unscientific to justify investment. The Myer Foundation was celebrating the centenary of Sidney Myer's arrival in Australia. Their Centenary Selection Committee decided that the concept was important for Australia and deserved funding. The intention of The Myer Foundation was to change the way Australians think about the ecosystems they use and depend on. Their support gave credibility to the research, and two projects were developed. "The Nature and Value of Ecosystem Services", was a research and communication network (Figure 1.1) funded jointly with CSIRO. The other, "Assessing Ecosystem Services in the Goulburn Broken Catchment" applied the ecosystem services concept in the Goulburn Broken catchment of Victoria (Figure 2.1). It was supported by The Myer Foundation, CSIRO, the Goulburn Broken Catchment Management Authority and Land and Water Australia. This report focuses on the Goulburn Broken work, but because the staff and communication activities of the projects over-lapped, we also report on the outcomes of the research and communication network project.

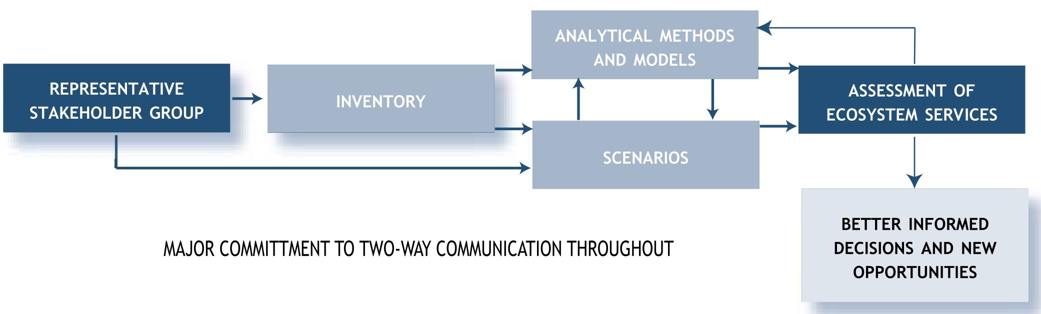
The formal aims of the Goulburn Broken project were to:

- estimate the benefits of ecosystem services at a range of spatial and temporal scales as a way to help policy makers, planners and land and water managers take account of the inter-relationships among a range of ecological, economic and social values;
- work with policy makers, planners, land managers, and industry and community groups to raise awareness of the values of maintaining ecosystem function;
- recommend policies and practices that maintain these values; and
- communicate project results widely.

Implicit but important additional aims of the project were to evaluate the concept, and to develop and test methods.

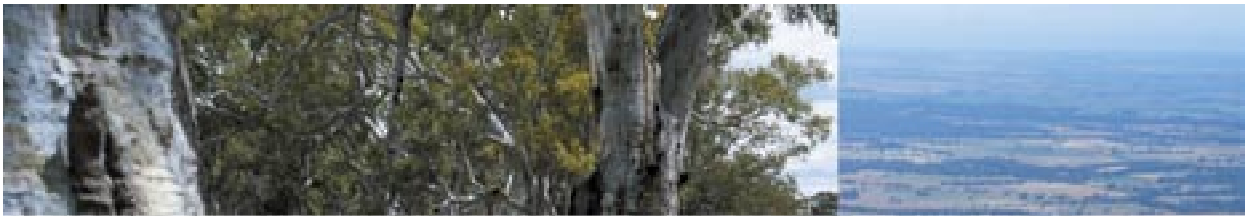
Our approach to the research is summarised in Figure 1.2. Key elements are: the engagement of stakeholders in participative research; an inventory process to focus on sets of ecosystem services and select case studies across a range of scales; the development of scenarios, and analytical methods and models for assessing ecosystem services. The project relies on existing disciplinary theories and data, and the role of our researchers is to link the theories, and reinterpret and synthesise the

Figure 1.2 Our approach to assessing ecosystem services



data from an ecosystem services perspective. Any insights and improvement in methods arising from the project are therefore at the system level, and not at the level of individual biophysical processes.

The structure of this report reflects its aims and our approach. In Section 2 we describe the Goulburn Broken Catchment and explain why it was chosen. Section 3 is about the relationships among natural capital, ecosystem services and sustainable development. In Section 4 we discuss the need to build an acceptably sound biophysical basis for the assessment of ecosystem services. Section 5 is about the central roles in the project of communication, marketing and participative research. Section 6 describes how we focused on particular case studies and ecosystem services across a range of spatial scales. The case studies are summarised in Sections 7–11. The first is a study of a dairy enterprise that uses a dynamic simulation non-spatial model. Our landscape scale study is an assessment of ecosystem services on a floodplain. It is based on a dynamic simulation model that incudes spatial heterogeneity at a fairly coarse scale. The next case study is an analysis of ecosystem services in a sub-catchment. It is based on a high-resolution spatial analysis of rule-driven native vegetation patterns. We evaluated the effects of these patterns on ecosystem services using a set of separate models and techniques. Our study of tourism and recreation is at a sub-regional scale. It used a deliberative poll, expert knowledge and multi-criteria evaluation, and tracked changes in participants' understanding of ecosystem services. Our input-output modelling of water, nutrients, employment and the economy spans the whole Goulburn Broken Catchment. Sections 12–14 synthesises our achievements, findings and recommendations in relation to the aims of the project.



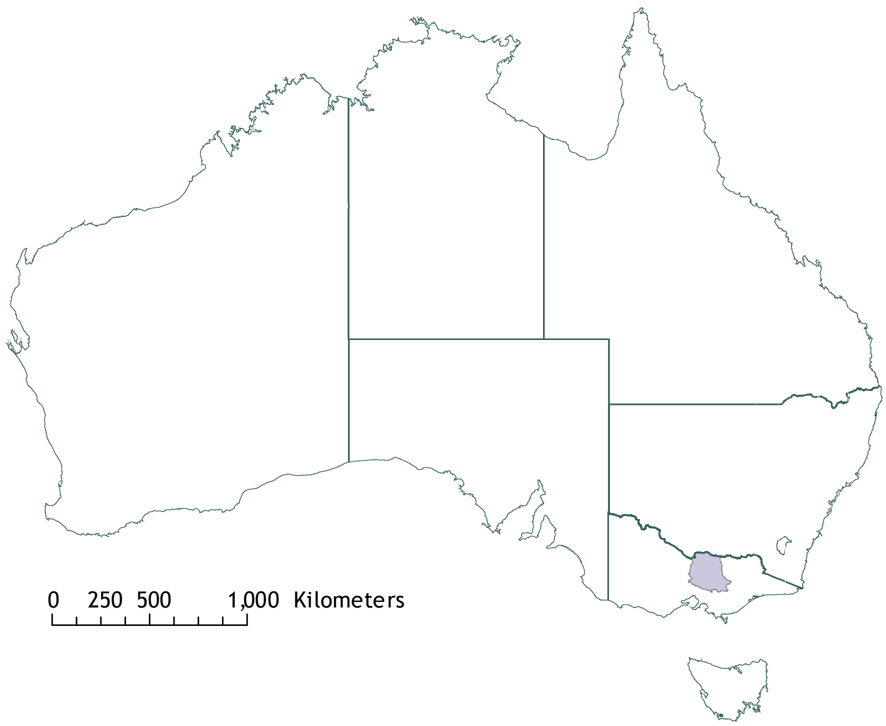
2 Economy and land use in the Goulburn Broken Catchment

2 Economy and land use in the Goulburn Broken Catchment

The Goulburn Broken catchment covers more then 2.4 million hectares, extending north from the mountains of the Great Diving Range, to the riverine plains of the Goulburn and Broken Rivers (Figure 2.1). The climate is temperate, with warm dry summers and cool, wet winters. Precipitation ranges from 1700mm in the south east, to 430mm in the north west and mean maximum and minimum daily temperature ranges at Seymour in the mid catchment (29.5^{0}C – 12.7^{0}C for January, 12.6^{0}C – 3^{0}C for July) are typical of the warmest and coolest months. The region comprises the Goulburn and the Broken river catchments. The combined mean annual flow of these rivers is approximately 3,300 gigalitres, of which about half is diverted for irrigation and urban consumption annually. Despite comprising only 2% of the land area of the Murray Darling Basin, the Goulburn Broken Catchment contributes 11% of the flow of the Murray River.

Approximately 71% (1.7 million hectares) of the catchment is private land, with the remaining 29% (0.7 million hectares) designated as various forms of public land reserves including more than 0.5 million hectares of national parks and state forests. Extensive clearing of native vegetation has occurred, particularly on private land, with more than 70% of native vegetation cleared. Forest and woodland types on the flat, fertile plains have been severly reduced, with many vegetation communities now less than 15% of their former extents (Goulburn Broken Catchment Management Authority 2003). Large tracts of native vegetation now occur only on mountainous public land in the upper catchment or the floodplains of the major rivers. Extensive clearing and development for agriculture has had profound impacts on native flora and fauna. One in ten plant and animal species in the catchment are threatened and many more are in rapid decline (Goulburn Broken Catchment Management Authority 2003). Clearing of native vegetation has also triggered serious degradation that now impacts

Figure 2.1 Location of the Goulburn Broken Catchment



on natural and economic capital assests. Salinity, both dryland and irrigation induced, deteriorating water quality and soil health, pest plants and animals threaten the viability of native and agricultural ecosystems in the catchment.

Land use is dominated by agriculture, with dryland agriculture covering more than 1.3 million hectares and intensive irrigated agriculture, particularly for dairy and horticulture, accounting for approximately 0.3 million hectares. Tourism and recreation, particularly in the forested upper catchment is emerging as an important land use. The human population of the catchment is currently 190,000 and is predicted to grow to 220,000 by 2022, with the majority of people living in the intensive agricultural region around Shepparton (Young 2001). Commodities from the catchment form a significant proportion of the agricultural exports from Victoria, particularly dairy and horticultural products. Total gross dollar value of production from the catchment in 2001 was $8,709m, and is predicted to grow to $9,620m in 2005. The largest industry in terms of dollar output, the dairy processing sector, provided 6,805 jobs (8.5 percent of the total jobs) in 2001 (Young 2001, and Section 11). More information on the structure of the economy is provided in Section 11.

The catchment is undergoing rapid social and economic change. Because of the proximity of the upper catchment to Melbourne, traditional farming is giving way to lifestyle and hobby farming, with local government areas in the southern catchment experiencing rapid population growth and restructuring of local economies (Goulburn Broken Catchment Management Authority 2003). In the mid catchment, declining terms of trade on traditional agricultural commodoties, an ageing farming population, the emergence of high value crops such as grapes, olives and berries, and inflated land values has seen a shift away from tradional agriculture in many areas. In contrast, the intensive irrigation region has experienced increases in agricultural production and a corresponding surge in investment in value adding. However the irrigation industry faces enormous challenges with rising costs, drought and increasing pressure to minimise externalities from their activities, particularly the impact of salt and nutrients on down stream users.

Why was the Goulburn Broken Catchment selected as a case study?

In many ways, the Goulburn Broken is typical of catchments throughout the intensive agricultural zone of southern Australia. Like all regional communities, the Goulburn Broken faces numerous challenges in balancing the need to maintain economically and socially viable rural communities while simultaneously meeting the expectations of the wider community to manage natural resources sustainably and with minimal down stream impacts.

There are also particular features about the Goulburn Broken catchment and its community not available to the same extent elsewhere. Its communication network is highly developed, a necessary feature for this project in which communication was a high priority. Further, community participation in decision-making is highly developed, with strong linkages between the community, government agencies and industry.

The community has established an ambitious vision for the catchment. Research is seen as a cornerstone to achieving this vision (Goulburn Broken Catchment Management Authority 2003). Incorporating the concept of ecosystem services is seen as a logical step in improving decision-making. The community and agencies in the catchment have extensive experience in developing and applying innovative approaches to natural resource management and the region has previously been the focus for numerous pilot programs. The catchment is also a major contributor of salt and nutrients to the Murray River and improved management of natural resources in the catchment has important implications for down stream users.

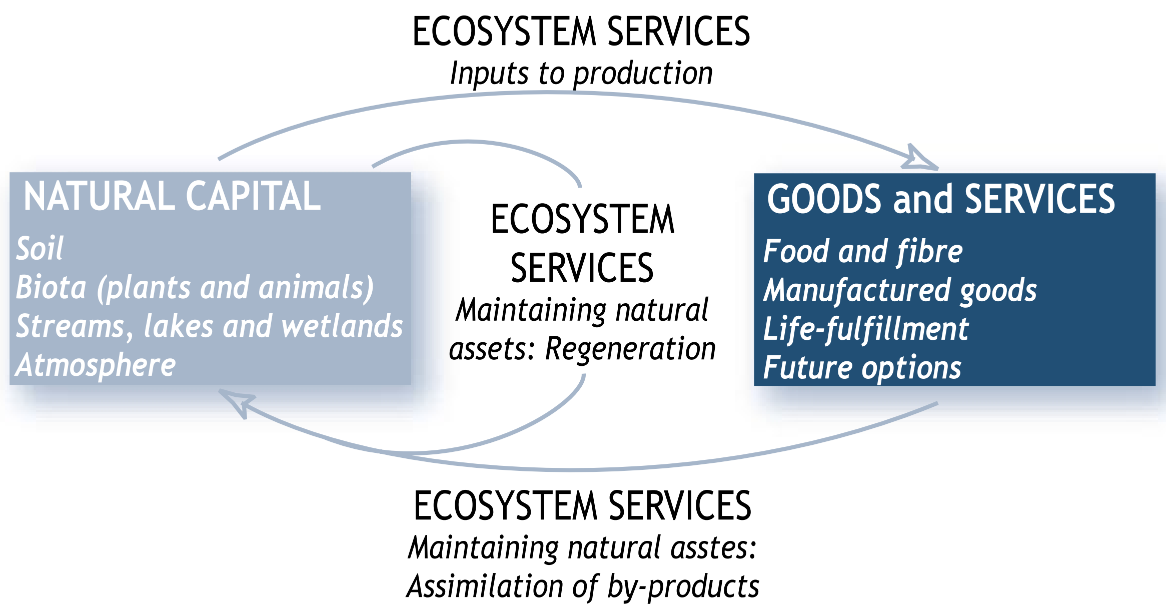
3 Development and the depletion of natural capital

3 Development and the depletion of natural capital

Development is the improvement of economic, social, cultural and environmental well-being of people (Coombs 2001). It requires the use of economic and social capital to extract value from natural capital. Economic capital is the physical means of production and distribution. Social capital includes knowledge and skills, the social arrangements for production and distribution, and for monitoring, taxing, regulating, encouraging and punishing individuals. Natural capital is the ecosystems that supply services to people (Figure 3.1).

The materials and energy embodied in social and economic capital originate in the sun, rocks or ecosystems (Patterson 2002). Some of the value extracted from natural capital is used to sustain current human well-being, and some is reinvested in social and economic capital for the further extraction of value from natural capital. Natural capital is the only type of capital that is self-sustaining. It is therefore the primary source of value. Historically, development has required economic growth, and growth has required an increase in the consumption of energy and materials (Meadows and others 1972). Under these conditions the laws of conservation of energy and mass result in inevitable degradation of natural capital (Georgescu-Roegen 1979), and sustainable development is not achievable. The contradiction of development is the degradation of natural capital even though human well-being and survival ultimately depend on its services. But it has already been demonstrated that at a national scale development, though not necessarily sustainable, can occur while reducing environmental impacts and the

Figure 3.1 Natural capital and ecosystem services



consumption of raw materials and energy (Tisdell 2001). Elements of sustainable national development include renewable energy and recycling technologies, service-oriented economies, efficient use of natural capital, and social reorganisation (Jansson and others 1994; de Graf and others 1995; Hawken and others 1999; Foran and Poldy 2002).

The balances among natural, social and economic capital vary between nations and regions. Australia is relatively well endowed with natural capital relative to its other capitals. The natural capital of Singapore is dwarfed by its economic and social capital, and clearly that nation depends for its sustainability on ecosystem services from natural capital outside its borders. Such transfers occur across many scales. Ultimately, the only scale at which critical balances among the capitals must be achieved is the scale of the planet. However, at finer scales some categories of natural capital are more important than others. They include those whose services cannot be: imported (e.g. floodplains and forests that regulate water flows and quality); substituted (e.g. native vegetation that provides aesthetic values); or reconstructed (e.g. wetland systems) (Collados and Duane 1999).

As economic and social capitals have grown in the Goulburn Broken catchment, natural capital has declined (Section 2). Because this project is regional in scope, our concern is not the sustainability of the region as an autonomous unit. Instead we focus on the efficiency of use of natural capital, and in particular upon reductions in natural capital that are already reducing net benefits to society or groups unnecessarily, or that threaten future well-being.

Many of the changes in ecosystems in the Goulburn Broken have been necessary for increasing human well-being, even in the long term. Clearing native vegetation for agriculture, for example, is about shortening food chains, simplifying food webs and diverting biomass to humans. Without simplification there can be no agriculture. At issue is the value and sustainability of outputs, the level and areal extent of simplification, the balance between industrial and ecosystem service inputs, and the losses of regenerative, stabilisation, assimilative and amenity services, as well as options for the future.

As understanding of the consequences of depleting natural capital has improved, the current balance of the three capitals appears to be inefficient and inequitable (Goulburn Broken Catchment Management Authority 2003; Binning and others 2001). Our researchers formed a partnership with the CMA because both groups believed the ecosystem services concept could contribute to the solution of land and water degradation and the identification of new development opportunities that combine natural, social and economic capital in efficient, equitable and more sustainable ways.

4 The production and valuation of ecosystem services

4 The production and valuation of ecosystem services

The objectives of this project required us to consider the values of ecosystem services. Valuation is necessary if markets and institutions are to be established to promote the efficient and sustainable use of ecosystem services. Political processes are the dominant way of implicitly valuing and actually allocating public resources in Australia (Godden 1997). Votes, party funding, jobs, environmental and economic impacts are among the influential factors. Neo-classical economics provides an explicit and normative approach to valuation, and cost-benefit analyses based on it do have some degree of influence on the political process. It assumes that consumers' willingness or ability to pay for a good or service, plus the value accruing to producers from selling it, represent the social value of the good or service. Where markets are absent, as in the case of most ecosystem services, values can be estimated from responses of representative individuals to structured questions (Bennett 1999).

One of the key assumptions of neo-classical valuation theory is that consumers have perfect knowledge about what they are paying for, including information about substitutes (Pindyck and Rubinfeld 2001). We

have already argued that lack of understanding is one reason why people degrade natural capital, and this includes unjustified optimism in the substitutability of economic capital for natural capital. The public is collectively ignorant about ecological processes and their role in sustainability, and is understandably confused because scientists are (equally understandably) in disagreement about the significance of processes such as salinisation and declines in biodiversity (Nunes and others 2001). An additional limitation of neo-classical valuations is that they result from short-term preferences, whereas investment in natural capital is for the long term. Our priority in this project was therefore to explore the long-term biophysical basis of value, which stems from the behaviour of ecosystems in time and space, and their responses to management. This is fundamental to estimating economic values, to understanding the degree to which other forms of capital can replace natural capital, and to making sound investments in sustainability.

Understanding ecosystem behaviour is fundamental to the establishment of effective market, incentive and regulatory schemes for sustainable use of ecosystem services, not only because it underpins economic valuation, but also because of risk and uncertainty. The current capacity of science to estimate changes in the output of ecosystem services in time and space in response to changes in management or disturbances is in most cases insufficient to justify investments in natural capital by landholders. It is also insufficient to allow governments to risk public funds or the political costs of wrong estimates. The priority is clearly to improve our understanding of how to make better estimates of how the flows of ecosystem services vary in time and space under various management and disturbance regimes. In economic terms, we set out to build "production functions" for ecosystem services as a necessary foundation for valuation and risk assessment (Acharya 2000, Barbier 2000, Bjorklund and others 1999).

A production function is the quantitative relationship among a set of physical inputs, human knowledge, skills and labour, technology and the physical quantity of an output. Economists use production functions as the link between biophysical resources and economic processes by attaching costs and prices to inputs and outputs. Economic production functions are usually simple equations that subsume multiple interacting processes.

Economic production functions have several deficiencies. They normally exclude ecosystem services. They typically assume fixed relationships between the ecological and the production system — they are non-dynamic — and cannot cope with non-linearity. They are usually non-spatial, and they rarely feed the consequences of production back to degradation of the ecosystem (Abel 1997).

An ideal ecological-economics production function would address all these deficiencies and include the capacity to estimate the impact on other values, including off-site impacts. It would also satisfy scientific standards of calibration and validation. Our work contributes to the quest for this ideal, each of our case studies contributing in a different way (Section 12).

5 Communication and participative research

5 Communication and participative research

Through this project our funders have made a large investment in broadening the thinking of a range of Australians about the value of the environment to people. We developed a communication strategy in partnership with Cox Inall Communications. It had the following components:

- encouraging two-way communication on ecosystem services between the research team and stakeholders through a variety of vehicles, including internet, email networks, workshops, public forums and media interviews and features;
- ensuring ecosystem services become central to national policy debates on natural resource management through developing networks with policy makers;
- creating understanding amongst landholders of the importance of ecosystem services — through regional communications plans and extension staff;
- progressing the creation of markets for critical ecosystem services, through developing networks with the investment community;
- creating national awareness of the ecosystem services project, through the media, partner networks and an education strategy; and
- managing risk from failing to address the critical issues, through stakeholder identification, information provision and fostering relationships through which we could become aware of potential issues, address them and learn from them.

We wanted to tell people what scientists have learned, and what we are learning, about the value of the natural world, but we wanted to go beyond that traditional approach to communication. Similarly, we wanted to avoid doing the research first and then looking for an application. Instead, we wanted to take our ideas to stakeholders at the beginning and learn with them how to modify the approach to best meet their needs. To do this, we had to create a community of stakeholders that was aware of the issues and could engage in dialogue. Therefore, we embarked on a program of not only awareness raising but also engagement with stakeholders to increase mutual understanding of the issues and possible solutions. This involved the use of the full range of media, and workshops and other public events within the Goulburn Broken catchment. The catchment program was linked to a national communication program.

We identified our key stakeholders as regional policy makers and influencers (including local government, State and Commonwealth policy and research agencies, industry and other community leaders and representatives of land management non-government organisations like Landcare and conservation groups). We had a desire to reach all Australians, and especially the youth of Australia, but we recognised early that our funding would not allow us to reach them all effectively.

Key stakeholders were not only engaged in regular workshops and focus groups, but many were also engaged in steering and management committees. In this way, key stakeholders became partners with a strong influence on how the project was done. This provided us with opportunities for enriching our research, as well as challenging us to integrate our scientific culture with other cultures.

It also was important to engage leading thinkers in the natural and social sciences, both within Australia and internationally, and we did this through visits from international researchers, workshops, and an exhaustive process of identifying major researchers.

6 Which services matter, and at what scale?

6 Which services matter, and at what scale?

The definition of ecosystem services we used in Section 1 identifies any contribution from ecosystems to human wellbeing or survival as an ecosystem service. Agriculture, for example, is utterly dependent on multiple ecosystem services from soil organisms that recycle nutrients, plants that stabilise landscapes and produce food and fibre, invertebrates that pollinate and regulate pests, and vertebrates that convert plants to food and fibre. Most agricultural inputs come directly from natural capital, and all do so ultimately. Although the concept has classified the complexity of services into sets to which most people can relate (Section 1), some additional priority-setting is required.

Each of the research groups in the Australian Ecosystem Services Research Network (Figure 1.1) has set its priorities in different ways, depending on their own capacities, the case studies that became available, and the priorities of stakeholders. We applied our 'Inventory' process to establish the priorities of our stakeholders (Binning and others 2001 — www.ecosystemservicesproject.org; Shelton and others 2001).

The first step was to work with local stakeholders to assemble a comprehensive list of products from ecosystems that people value in economic or other terms (intellectual, spiritual, cultural aesthetic). The ecosystem services involved in producing these goods were identified in workshops with community members and scientists, and by local experts working as consultants. The services were ranked in relation to three assessment criteria:

- the overall importance in terms of the revenue earned by the products using the ecosystem service, the perceived importance of the service to the production of the products, and the impact of the land-use/industry on the sustainability of the service;
- importance at the margin — the impact of a small change in a service on production of goods, or maintenance of natural capital; and
- manageability — the capacity to manage the land-use/industry to ensure the sustainability of the service.

Three levels of ranking were derived:

- low — not significant to the catchment;
- medium — significant; and
- high — critical to the future of the catchment.

The inventory process identified the priority ecosystem services as: pollination; human fulfilment; regulation of climate; pest control; maintenance of genetic resources; maintenance and regeneration of habitat; provision of shade and shelter; filtration and erosion control; maintenance of soil health; provision of healthy waterways; regulation of river flows and ground water levels; waste absorption and breakdown (Table 6.1).

Individual ecosystem services were then grouped into nine issues. In consultation with the Catchment Management Authority, a set of five case studies was selected to address them (Table 6.2; Sections 7–11)

The case studies (Figure 6.1) were chosen to span social, economic and spatial scales because it is useful to view the Goulburn Broken catchment as a social-ecological system containing interacting sub-systems — enterprises, industries, landscapes and sub-catchments, for example. By analysing case studies at the different scales we can estimate the flows of ecosystem services from natural capital at each scale. However, information, dollars, water and other materials flow among these sub-systems, so that changes in natural capital at one scale affect processes at other scales (e.g. changes in patterns of remnant vegetation on multiple properties in a region affect the conservation of populations of native species across the region or more broadly). Our preliminary quantification of flows of ecosystem services at selected scales can contribute to a plan for strategic investment in natural capital that takes explicit account of scale effects. We return to this issue in Section 14.

Table 6.1 Priority ecosystem services related to landuses in the Goulburn Broken Catchment

Ecosystem service	Land Use Industry											
	Dairying - on-farm	Friut and grapes	Vegetables	Grazing	Crops	Intensive animals	Forestry	Food processing	Housing	Water production	Recreation	Areas of culture/ future options
Pollination		■										
Life-fulfillment	■			■					■			■
Regulation of climate	■	■				■		■				
Pest control		■	■	■	■							
Maintenance and provision of genetic resources				■								
Maintenance and regeneration of habitat		■	■	■			■		■		■	■
Provision of shade and shelter	■	■		■	■				■			
Maintenance of soil health	■	■	■	■	■							
Maintaining heathy waterways	■	■		■			■	■		■	■	
Water filtration and erosion control			■	■	■					■		
Regulation of river flows and grounwater levels	■	■			■					■	■	
Waste absorption and breakdown	■	■	■	■	■	■		■	■	■	■	

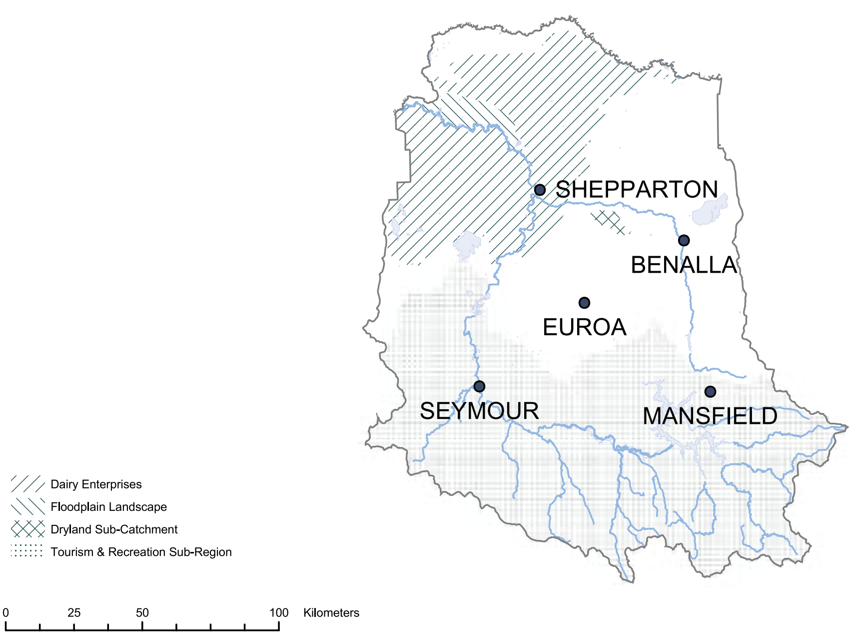
Note: Dark squares indicate links between services and landuses.

Table 6.2 How the case studies addressed key issues

Key Issues	Case studies				
	Dairy enterprise	Floodplain landscape	Dryland sub-catchment	Tourism and recreation sub-region	Regional economy, water and nutrients
Integrating management across ecosystem services	✓	✓✓	✓✓	✓	✓
Managing land use intensification	✓				✓
Managing transitions in land use	✓	✓✓✓	✓✓✓	✓	✓
Managing vegetation — a hub in the landscape		✓✓✓	✓✓✓		
Managing cultural, heritage and option values				✓✓	
Maintaining soil health	✓		✓✓		
Accounting for the value of non-agricultural land and water uses		✓✓✓	✓✓✓	✓✓✓	
Management of water and salinity	✓	✓✓✓	✓✓✓		✓✓✓
Anticipating and adaptively managing emerging issues	✓✓	✓✓	✓✓	✓✓	✓

Note: the number of ticks shows the extent to which the case study addresses the issue — the more ticks the greater the extent.

Figure 6.1 Location and scale of case studies in the Goulburn Broken Catchment



7 Ecosystem services from dairy systems

7 Ecosystem services from dairy systems

Collaborators: Jenny Langridge and Brian Walker

The aim of this case study is to develop a model of the milking area of a dairy farm as a tool for exploring the 'value' of ecosystem services produced at a farm scale.

7.0 Case study highlights

Project outputs include:

- a dynamic model of the milk producing area on a dairy farm with an emphasis on ecosystem services.

Key observations from workshops and analyses are:

- the greatest variation between dairy management practises is in feed supplementation and water use efficiency;
- there is a trend among dairy enterprises for increasing water use efficiency;
- water re-use systems on high input farms increase milk production and reduce nutrient runoff;
- little is understood of the current state of the soil ecosystem and critical thresholds on different farm types but there is evidence from other research that once a system has reached a threshold (i.e. ability to absorb waste) recovery is slower than the original rate of degradation;
- little empirical knowledge exists of the effect of soil organism diversity on soil fertility and decomposition although other research suggests that as diversity declines so does a system's resilience — the ability to adapt to change;
- increased herd productivity through the provision of shade and shelter is offset by the cost of establishment. However if trees are used instead of artificial shelter there is the potential for enhancement of other ecosystem services such as carbon sequestration and biodiversity;
- the impact of shade and shelter on milk production may be more significant in the future due to climate change; and
- the role of natural pest control is unclear but it may be beneficial to production.

Key considerations are:

- soil organism activity and fertiliser application are substitutable but their effect on fertility is not equal;
- gaps in knowledge of processes such as the role of organisms in nutrient cycling underlying key services hinder improved economic and environmental returns;
- in some situations both economic and environmental gains could be made through better management of some ecosystem services such as provision of shade through establishment of trees; and
- some ecosystem services, the maintenance and regeneration of habitat for example, are not provided by the milking area of a dairy farm due to the intensity of production. Such services need to be maintained at a broader scale. Other services, such as maintenance of healthy waterways, important to downstream water users, can be managed at the farm/ enterprise scale.

7.1 Background and issues

Dairying was identified in the inventory (Binning and others 2001; and Section 6) as one of the key industries in the Goulburn Broken Catchment, with 112 000 hectares producing 840ML of milk annually at a gross value of $453 438 000 (1996 estimate). Dairying uses water from the irrigation channel system which is applied either by regular flooding or to a lesser extent from spray systems. Key ecosystem service issues for dairy farms, identified in the inventory and which can be managed were:

- "provision of shade and shelter" from trees — Heat stress in animals has many adverse effects on livestock, including reduced reproductive efficiency, decreased live-weight gain and reduced milk production;
- "maintenance of soil health" — Soil fertility has been enhanced by fertiliser use and in particular by nitrogen application over the last 10 years, however the role of soil organisms in promoting the efficient cycling of nutrients is poorly understood. Compaction and water logging of soils through irrigation, trampling, farm machinery and cultivation all contribute to the decline of soil health. Management of stock and irrigation can minimise these effects;
- "waste absorption and breakdown" and "maintenance of healthy waterways" — A major issue to the wider community is nitrogen and phosphorus loads in waterways. Dairy farms contribute to this load through fertiliser application and irrigation. Soil erosion associated with compacted laneways and stock tracks exacerbate the problem by mobilising nutrients. Improved nutrient management practices could minimise the problem;
- "regulation of river flows and ground water levels" — The availability of irrigation water to dairy farms is now a major issue in some regions, and will undoubtedly be a growing concern in the future. Salinity, associated with rising water tables, is reducing the area of productive farming land and given the lag period associated with ground water movement will continue to do so even if action is taken to reverse the trend. Dairy farms can contribute to the salinity problem as accession water from rain and irrigation beyond the root zone is added to water tables; and
- "regulation of climate" — Specific issues concern greenhouse gas emissions. Animals within the Goulburn Broken Catchment produce methane emissions equivalent to about 1480kt CO_2 per year, an additional 340kt CO_2 per year is generated from the pasture and is exacerbated by nitrogen fertilisation, water logging and legume pastures. Animal waste contributes to nitrous oxide emissions equivalent to approximately 160kt CO_2 per year.

Although the importance of these services to the dairy industry or wider catchment are recognised, few studies have looked at dairy farming as a system. Existing models developed for the dairy industry, including DairyPro (Kerr and others 1999), DairyMod (Johnson pers. com. http://www.imj.com.au/dm/), P-Opt (Nexhip and others 1997) and the Nitrogen Decision Support System (Eckard 2000), are useful in answering particular questions and examining aspects of production on a dairy farm but they are not suitable for exploring ecosystem services and interactions between them. The following sections describe our approach.

7.2 Methods and outputs

7.2.1 Overview

The development of a dairy production model was our first attempt at analysing interactions among key ecosystem services at a fine scale. This approach was taken to gain a greater understanding of these interactions and how these might change under different management regimes. Using a production function approach, but with the inclusion of ecosystem services and exclusion of social and economic capital, we were able to identify the major outputs and inputs of concern on the 'milking area' (area grazed by milk producing cows) of a dairy farm (Table 7.1). Through workshops and stakeholder input, the interactions of inputs and outputs were explored and scenarios developed. A simulation model of the milking area of a dairy farm was developed to capture these interactions and explore scenarios.

7.2.2 Scenario development

Two workshops were run in the Goulburn Broken Catchment in August and September 2000 to identify gaps in knowledge, explore management scenarios and to refine the model. Attendees at the workshops included

Table 7.1 Outputs and inputs from dairy farms

Output "Goods" Production value		Input "Services" Production Costs (substitution options)
	ECOSYSTEM SERVICES APPROACH	
Milk production		*FEED*
		feed type (hay, silage, grain, pasture, dairy meal)
Off farm water quality		soil water (irrigation, rainfall)
Methane		soil fertility (fertiliser and/or **soil biota activity**)
Nitrous oxide	$= f$	[weed control (herbicides and/or **stocking rate management**)]
Carbon-store		[pest control (biocides and/or **control by natural enemies**)]
Biodiversity		*WATER (FOR COWS)*
Salinity/water table depth		pollution (biocides,herbicides, fertiliser, filtration plant and/or **natural filtration**)
		ANIMAL HEALTH
		temperature/wind control (sprinklers, manufactured shelter and/or **tree cover**)

Note: The biophysical processes in bold are those not typically considered in existing production models.

dairy researchers from the Department of Sustainability and Environmental Kyabram Dairy Centre, and the Institute of Sustainable Irrigated Agriculture, and dairy farmers. There was consensus at these meetings that the main variation between dairy farms (considering only the milking area) was in the level of feed supplementation and in their water use efficiency which is influenced by the timing and amounts of water and fertiliser applied and the effectiveness of water re-use. It was believed that in future although there would be more high input farms, these farms would have more effective water re-use systems and hence high water use efficiencies. The dairy model described in the next section is able to explore a range of management practices associated with these key inputs on a dairy farm. Our stakeholders classified dairy farms in the region as low input, high input, and high input dairy farms with efficient water use.

7.2.3 Model development and outputs

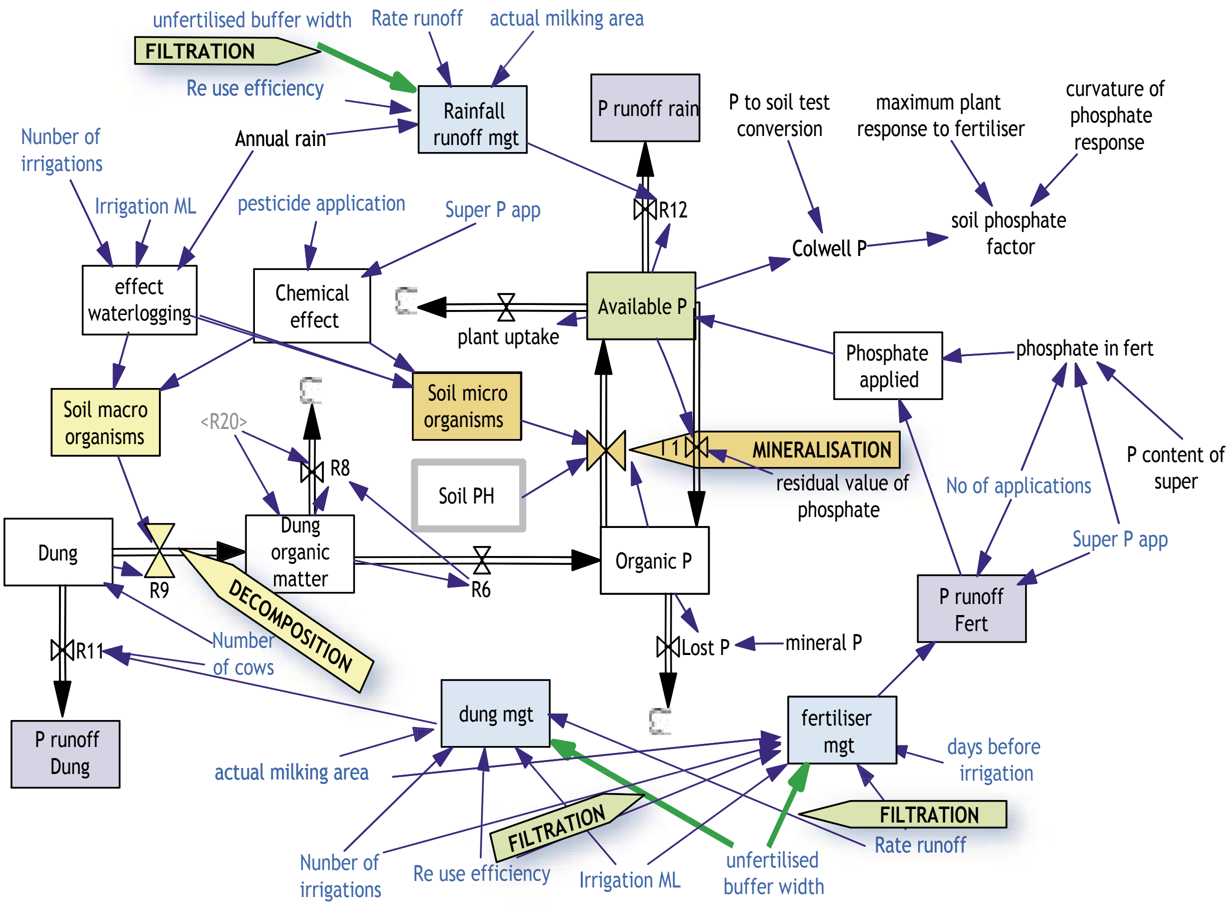
The simulation model was developed within the Vensim simulation environment (Ventana Systems Incorporated 2003) and was most applicable to an irrigated dairy pasture system consisting of annual and perennial grasses. It combined empirical relationships, biophysical processes and hypothetical relationships (explored with dairy researchers). It included:

- a simple empirical pasture growth routine (using key elements of pasture growth models as explored by White and Walker (2001);
- a milk production routine (Halachmi and others 1997);
- nutrient dynamics and in particular P cycling (based on Powlson 1989; Nexhip and others 1997; Eckard 1998; Bush and Austin 1999; Eckard 2000; Eckard and McCaskill 2000;);
- a soil pH routine (White and Walker 2001);
- fertilizer and irrigation routines (Nexhip and others 1997; Bush and Austin 1999) including consideration of the role of soil organisms;
- heat stress routine (Davison and others 1996; Jones and Hennessy 2000); and
- greenhouse gas calculations (Eckard and others 2000).

Ecosystem services that were not considered important by stakeholders were not included. They included pest and weed control. Biodiversity and aesthetic goods from dairy farms, although recognised in particular by the wider community and included in initial conceptual models, were not operationalised. The broad farm types identified by our stakeholders were supplemented by data collected by a survey of dairy farms in Northern Victoria and Southern NSW (Armstrong and others 1998), and one in the Goulburn-Broken Catchment (Cairns and others 2000).

As an example of the model structure, Figure 7.1 shows elements of the phosphorus routine with various ecosystem services highlighted. Some management actions including the maintenance of an unfertilised buffer strip at the ends of irrigation bays, number of days after fertiliser is applied that pasture is irrigated and number of irrigation events in a year in association with inputs to production (e.g. superphosphate application, quantity of irrigation water applied and stocking rate) tempered the effectiveness of ecosystem services such as filtration. Although soil micro and macro-organism diversity is included conceptually in the model the role it plays in the maintenance of soil health via mineralisation and decomposition and the effects of management on these organisms is a key knowledge gap. Although studies have looked at aspects of soil organism activity (eg. earthworm activity-Yeates and others 1998; Larinck and others 2001; effect of chemicals on soil organisms — Gyldenkaerne and Jorgensen 2000) information is patchy and

Figure 7.1 The phosphorus subroutine



Note: Ecosystem services highlighted in block arrows.

not appropriate for the type of system we are studying here. It was not possible to undertake field research in this study and even if the resources were available as is pointed out by Giller and others (1997) numerous difficulties in sampling and classification obstruct the measurement of soil biodiversity.

As we do not know enough to determine the condition of the soil ecosystem on different dairy farm types we can only hypothesise what may happen under current, or with different, management regimes. Thresholds are not identified and it could be that although underlying processes appear to be currently stable or changing in a predictable way, crashes may occur in the future, and recovery may take longer than degradation (hysteresis effect). Stakeholders assumed that the more dung the more worms and other organisms, hence the service of decomposition is one that is generally taken for granted. It is possible that above an unknown threshold the rate of accumulation of dung exceeds the ability of the decomposers to process it. If so the service of decomposition would be a higher concern to the dairy industry. The model was therefore run to test the sensitivity of outputs to changing the weighting of soil organism activity and to illustrate the opportunities or future hazards that may have been overlooked.

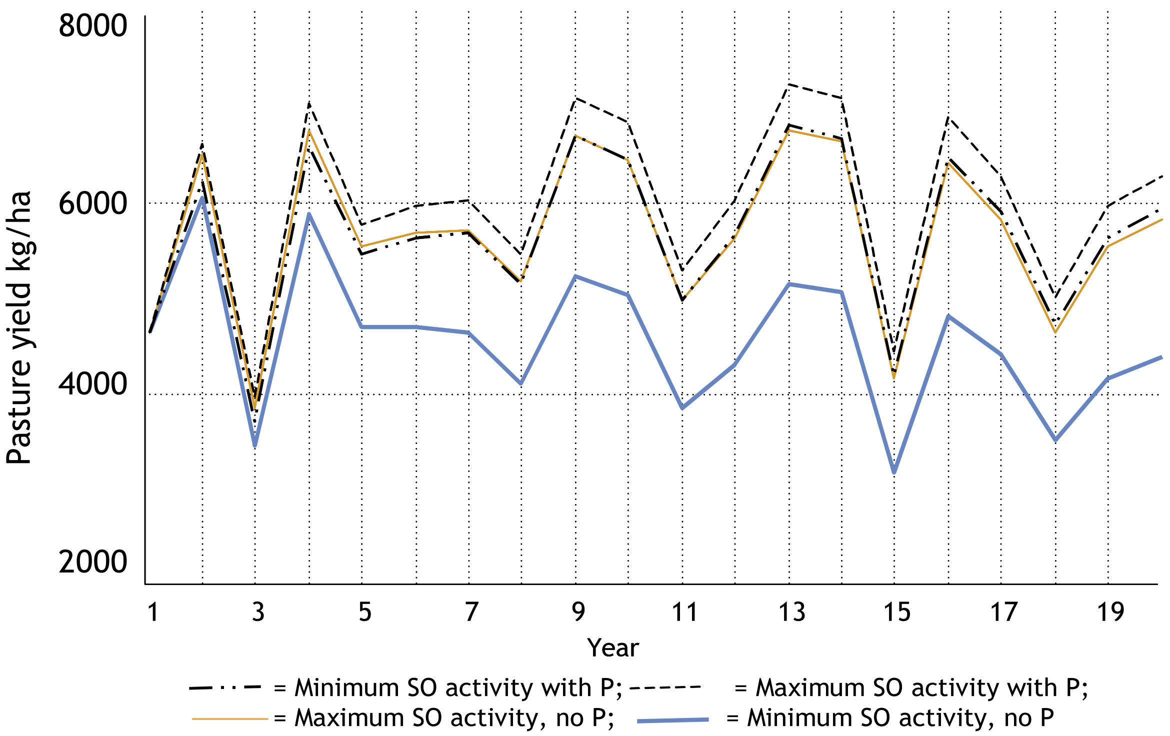
Figure 7.2 shows the results of four hypothetical scenarios with a soil organism effectiveness weighting at a maximum and minimum level and with either no phosphorus application or an application of superphosphate at a low rate of 200kg/hectare/year. When phosphorus is not applied but when soil organism activity is at a maximum, pasture yield is similar to that when soil organism activity is at a minimum but superphosphate is applied. When phosphorus is applied there is some advantage in having high soil organism activity but the effect is less significant and this is more apparent as phosphorus application is increased.

7.3 Interactions and trade-offs among ecosystem services

Simple farm finances were included in the model and compared with other outputs under various management scenarios. Table 7.2 shows that the addition of a water re-use system to the high input farm increased income via increased milk production through the recycling of nutrients. It also reduced nitrogen and phosphorous leaving the farm in runoff and decreased their impacts on water quality.

The increased income for high input farms with water re-use and the provision of shade when compared to the scenario without shading is attributable to the additional 15000 litres of milk produced as a consequence of reducing temperature stress in cows by the provision of shade. This increased income would be offset by the cost of either planting trees and/or constructing shelters and perhaps loss of productive pasture but if a climate change scenario for the Goulburn Broken Catchment were considered it may be that the benefits would outweigh the costs. If shelter were provided by carefully designed revegetation there may be some additional benefit in terms of carbon sequestration and perhaps some biodiversity benefits.

Figure 7.2 The results for a low intensity dairy farm for four hypothetical scenarios



Note: SO = soil organism activity; P = 200 kg/hectare/year phosphorus application

Table 7.2 The value of output of goods from the dairy model under four management scenarios

Value of Output Goods	High input	Low input	High input + reuse	High input + shade + reuse
Variable costs[1] ($/farm/year)				
Milk	316 119	158 970	319 711	323 160
P fertiliser*	14 930	7 204	14 930	14 930
N fertiliser*	3 254	0	3 254	3 254
Irrigation*	16 254	6 972	16 254	16 254
Total cost supplement	25 232	17 316	21 782	21 782
Other costs (topping, harrowing, weed/pest control, channel maintenance, pasture renovation)	18 000	9 500	18 000	18 000
Net income	238 449	117 978	245 491	245 491
Other "Goods" Ecosystem outputs				
Biodiversity/conservation value[2]	?	?	?	?
Carbon store under pasture (tonnes/farm)[3]	37 600	18 500	40 400	40 400 [3]
CO_2 discharge (tonnes/farm/year)	100	52	100	100
Methane discharge (tonnes/farm/year)	28	14	28	28
Total P loss (kg/farm/year)	530	300	130	130
Total N loss (kg/farm/year)	6 100	2 800	4 400	4 400

Notes: Scenarios are: high input; low input with no water reuse system; high input with a 60% efficient water reuse system and with the provision of shade. Items in **red** are costs either to the farmer or to the wider community. Items in **black** are either income or public goods.

[1] not including labour
[2] unable to be estimated with any confidence but probably of minor value on the milking area
[3] if perennial woody vegetation is maintained or established the carbon store will be greater than that under pasture alone

7.4 Conclusions and lessons learned

Once the usual factors influencing milk production were included in the model, researchers and stakeholders were asked to identify important ecosystem services. While building these into the model, however, it became clear that there was much uncertainty about some important underlying processes.

Presentation of the ecosystem services model of a dairy system to the stakeholders in the Goulburn Broken Catchment has created considerable discussion and useful insights. It also resulted in stakeholder discussions as to what ecosystem services were missing and how to quantify them. It proved a useful communication tool and for some stakeholders it clarified the importance of the ecosystem services concept. Some concerns were raised about the simplifying assumptions of the economic and biodiversity analyses (Table 7.2). These will be valid concerns if the model is developed further, but at this stage of development the simplified assumptions are appropriate.

Our modelling was deliberately restricted to the scale of the 'milking area', which is land where the cows are kept, fed and milked during their lactations, and at this scale, given the state of knowledge at the time of the study, the ecosystem service concept added little to on farm management for increases in milk production for two reasons:

- the nature of the milking area imposes limits on ecosystem service enhancement. For example, clearing of native vegetation from the milking area has reduced above-ground biodiversity to a fraction of its pre-settlement levels and chemical and high organic inputs have altered the ecosystem above and below the soil surface. Opportunities to improve production through enhancing ecosystem services from the milking area are therefore limited. For instance, although there are multiple benefits with establishing native shade trees, in many milking areas trees do not survive because of irrigation, or cannot be positioned without hampering farming operations. Artificial shade in this case may be the best solution; and
- poor understanding of process at a fine scale limits analysis. Maintenance of soil health (and hence fertility) is highlighted as the key ecosystem service contributing to milk production on a dairy farm but our understanding of the role of soil organism diversity in nutrient cycling is limited and critical thresholds were not identified. Therefore our analysis was not able to explore with any confidence the indirect effects of current management on the efficiency of nutrient cycling.

Our analysis however was able to look at some of the tradeoffs through use of filter strips and water re-use systems to reduce nutrient runoff. Water re-use systems indirectly increased milk production through increasing water use efficiency and recycling of nutrients but without a better understanding of soil processes we did not believe further development of the model would add greatly to our understanding. At a broader scale dairy farms depend on ecosystem services for pest and weed control, regulating and purifying flows of irrigation water, balancing carbon outputs, capturing the nutrients that escape the farm, producing fodder and shade for dry cows, and supplying nutrients and moisture for growing crops used for supplementary feed. While some of these ecosystem services are provided by other systems (e.g. forested upper catchment area) some are captured on dairy farm 'out blocks', which are satellites to the milking area but separated from it in space and are not directly involved in milk production. Uses of outblocks include cropping, agistment, over-wintering and dryland grazing. Methods for evaluating ecosystem services on outblocks are described in the floodplain and sub-catchment case studies (Sections 8 and 9). The CMA's strategy for investment in natural capital needs to promote investment at catchment scale in the maintenance of ecosystem services that support an industry with high multipliers for dollar output and employment (Section 11). There is a need to strengthen policies (e.g. water markets, water property rights, water quality monitoring and regulation, tradable pollution permits) that promote water re-use and nutrient retention on farm. There is also a strong case for strengthening or establishing policies (e.g. offset schemes) that promote establishment of native vegetation on outblocks (or elsewhere) to compensate for greenhouse gas emissions from, and lack of habitat for native species on the milking areas.

8 Assessing ecosystem services on the lower Goulburn River floodplain

8 Assessing ecosystem services on the lower Goulburn River floodplain

Collaborators: Jenny Langridge, Russell Gorddard, Art Langston, Paul Ryan, Mark Howden, Nick Abel.

The aim of this case study is to evaluate changes in ecosystem services and the economic costs and benefits of production on the northern floodplain of the lower Goulburn River under scenarios of future land management

8.0 Case study highlights

Project outputs include:

- tables of transitional change in vegetation response to different land management including estimates of changes in Habitat Hectare Scores;
- a dataset of the extent and duration of flooding events across the floodplain as a time series;
- GIS algorithms for aggregating mapping units while maintaining the integrity of spatial pattern; and
- a spatially explicit dynamic model for generation and evaluation of future management options on the floodplain.

Key observations from workshops and analyses are that:

- significant information deficiencies exist, particularly about the floodplain scale behaviour of the system and available data is of variable quality;
- key ecosystem services have values that are significantly affected by management;
- these ecosystem services are underpinned by the same biophysical processes;
- the key determinant of woody vegetation on the floodplain are frequency and extent of flood controlled germination events, the flood regime, competition from herbaceous species, survival and growth of germination cohorts; and
- increases in vegetation biomass is most sensitive to changes in the management regime in the medium term (20–30 years) settling down in the longer term as the woody vegetation matures.

Key considerations are that:

- the flood plain is a highly interconnected system — the ecosystem services framework has provided some insights into this complexity, identified the key drivers of the system and is a good basis for exploring trade-offs;
- improved management of a single umbrella service (regulation of river flows) has implication for the provision of a suite of other services many of which may have substantial benefits or returns to the community;
- as extremely long time scales are involved in the vegetation change process the benefit from managing for ecosystem services varies over time with some benefits not being fully realised in a conventional management time frame; and
- the significant interconnections between different goods and services of the floodplain mean that issue by issue policy making is inappropriate.

8.1 Background and issues

The purpose of the floodplain case study was to evaluate changes in ecosystem services and the economic costs and benefits of production on the northern floodplain of the Goulburn River under scenarios of future land management. The scenarios included changes in flood regime and varying mixes of grazing, cropping and conservation land use. The case study adds to previous cost / benefit analyses of the floodplain (PriceWaterhouseCoopers 2001) by developing an understanding of the floodplain as a linked economic and ecological system. This is intended to facilitate consideration of ecosystem services in future natural resource decision processes. This report presents the methodology and some initial results, however due to factors external to this project, the dataset required for the completion of the modelling is not currently available. Further modelling will be completed when this dataset is acquired.

The Goulburn is one of Victoria's largest rivers, delivering on average more than 1400 gigalitres of water to the Murray River each year (Victorian Water Resources Data Warehouse 2003). The capacity of the river channel progressively decreases as the river flows north from Shepparton towards the Murray, declining sharply from 185,000 megalitres/day at Shepparton to just 37,000 megalitres/day at the Yambuna Choke, a natural constriction near the confluence of the Goulburn with the Murray River. Under natural flood conditions, once channel capacity is surpassed the excess flows spill out of the Goulburn River channel on to the natural floodplains to the north and south of the river. On the northern floodplain a series of creeks and natural depressions conveyed floodwaters directly to the Murray River.

Within this northern floodplain area the predominant agricultural activity is rotational 'dry land' cropping and grazing (mostly beef and some sheep for meat and wool) with some minor areas of irrigated cropping. Property sizes range from a few hectares to over 1500 hectares. Crops include hay, rice, wheat, barley, oats and canola. Most agricultural activity is on cleared land although about 16% of land seasonally grazed is a mixed pasture with a light native tree cover (Earth Tech 2002). A significant proportion of the floodplain area is used to supplement farming activity elsewhere in the region. For example, dairy farmers raise hiefers on the floodplain before bringing them into the milking herd and they use the area for 'drying out' milkers during the winter months (Earth Tech 2002). Approximately 20% of the floodplain is public land, which includes streams and adjacent land. Native vegetation cover is generally greatest on the public land.

In response to a series of large floods in the late 1890s and early 1900s levees were progressively constructed adjacent to the Goulburn River to minimise the impacts of floodwater on adjoining land. The levees, in conjunction with a regulator at Bunbartha (Loch Garry), provide protection to both agricultural land and residential areas under minor to moderate flooding conditions. A number of problems have arisen as a result of the levees:

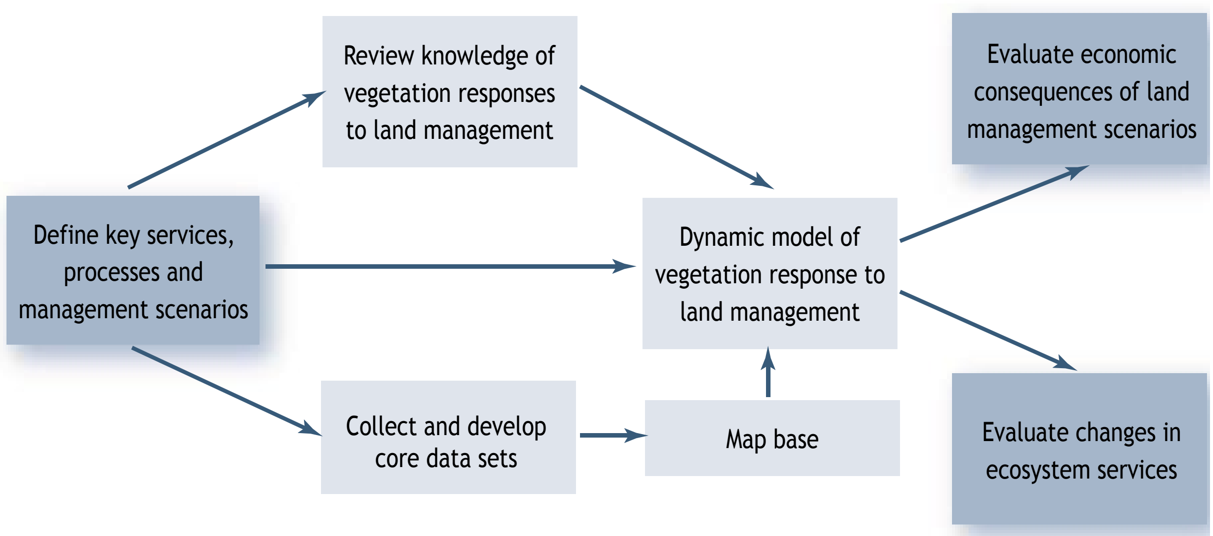
- the levees fail approximately every ten years causing damage to the levee system, losses to agricultural production, and levee maintenance costs;
- flows in the channel of the Goulburn River are higher than under natural conditions causing considerable river bank and bed erosion;
- the increased power of the water has lead to increased stream turbidity, nutrient loads, degradation of riverine ecosystems and loss of native species; and
- less frequent flooding on the floodplain has reduced water flow into ephemeral streams and wetlands leading to declines of in-stream habitat and changes in vegetation communities.

Random levee failure during 1993 flooding caused more than $20 million damage in lost production and infrastructure repairs and resulted in considerable social disruption (Goulburn Broken Catchment Management Authority 2000). In response, the Goulburn Broken Catchment Management Authority (CMA) proposes to reutilise the floodplain on the northern side of the Goulburn River by removing sections of existing levees and converting Loch Garry to a spillway. The proposal involves the compulsory acquisition of approximately 10,000 hectares of private land and constructing low level bunds to the north and south of the floodplain to create a floodway of approximately 13 700 hectares. Stakeholders at various project workshops in the catchment identified the floodplain as a high priority for further investigation using the ecosystem services framework. Stakeholders were particularly interested to identify the full range of benefits that may be gained from utilisation of the floodplain ecosystem.

8.2 Methods

A framework was developed for evaluating changes in ecosystems services under various flooding regimes (Figure 8.1). Key ecosystem services, processes and issues were identified through discussions with catchment managers and through a workshop process. A spatial database was compiled including soil characteristics, existing vegetation, flood duration and extent, and potential future vegetation. A map base was created for modelling land management scenarios. An extensive literature review as well as interviews with local experts yielded tables of transitional change in vegetation in response to land management. These were used to calibrate vegetation changes in the dynamic spatial model, we built to evaluate ecosystem services. The model was run to explore spatial and temporal changes in ecosystem services in alternative floodplain futures.

Figure 8.1 The framework for evaluating ecosystem services on the lower Goulburn River floodplain



8.2.1 Defining key services, processes and management scenarios

Through a workshop process stakeholders identified key ecosystem services and goods provided by the floodplain ecosystem, key biophysical processes and defined scenarios of future land use and management. The equivalent ecosystem services as defined in "Natural Assets: An Inventory of Ecosystem Goods and Services in the Goulburn Broken Catchment" (Binning and others 2001) are included in parentheses and are adopted for consistency in the remainder of this section. Ecosystem services included flood mitigation (regulation of groundwater and river flows), improvements in water quality (water filtration and erosion control), maintenance of biodiversity (maintenance and regeneration of habitat), and above ground carbon sequestration (regulation of climate). Goods produced on the floodplain included pasture for grazing, crops and trees for forestry.

In quantifying the services several issues were addressed:

- flooding by its nature is extremely variable in time and space, this in turn drives significant variation in flood-related services across the floodplain;
- many of these services are underpinned by the same biophysical processes, particularly vegetation development, therefore management changes may affect multiple services at once, so ecosystem services cannot be usefully studied in isolation to each other; and
- there are extremely long time scales involved in vegetation change processes; River Red Gums, for instance can live in excess of 350 years with individuals reaching over 1000 years (Jacobs 1955; Cuddy and others 1993). Sustainable management of the floodplain requires consideration of these long time frames.

8.2.2 Collection and development of datasets

Soil data were provide by the Victorian Department of Sustainability and Environment's Centre for Land Protection Research extracted from a dataset generated for the Goulburn-Broken Regional Development Program: Land and Climatic Suitability Criteria (Robinson 2001). They were extrapolated from existing soil mapping (Shepparton Irrigation District (Skene and Freedman 1944), County Moira (Butler and others 1942), Murray Valley Irrigation Area (Johnston 1952), Deakin Irrigation Area (Skene 1963). Extrapolation used soil pits, landscape pattern, and radiometric data.

Data on flood duration and extent were provided by Water Technology Pty. Ltd. as part of a broader project to assess the impacts on the floodplain of changing the flood regime. Floods were modelled using the MIKEFLOOD modelling tool. It combines a one dimensional stream model with a two dimensional landscape model of water flow. The landscape was defined using a combination of 10cm vertical resolution laser digital elevation model (DEM), stream channel lines and profiles, levee lines and infrastructure (eg. culvert, bridges and regulators). Due to issues beyond Water Technology's control the project is running well behind schedule. Because of this we have only been able to use the pre-1750 flood models. These have been produced for 2, 5, 10, 20, 50, 100 and 200 year average recurrence intervals (ARI). As discussed elsewhere this has placed major constraints on how far the ecosystem services dynamic model could be developed at this time.

Flood events between 1921 and 2001 were identified from Shepparton gauging station data (reference number 405204). The number and duration of each 'average recurrence interval' (ARI) event in any one year were calculated from hydrograph data for the Shepparton station (Conservation and Natural Resources 1995). ARI is the average time in years between flood events of a specified

Table 8.1 Relationship between vegetation classes used in this study and Victorian Ecological Vegetation Classes

Project Vegetation Class	Victorian Ecological Vegetation Class
Black Box	Black Box Chenopod Woodland
	Black Box Chenopod Woodland/Lignum Wetland Mosaic
Drainage Line	Creekline Grassy Woodland
	Drainage Line Complex
Gilgai Woodland	Plains Grassy Woodland/Gilgai Plains Woodland/Wetland Mosaic
	Riverine Grassy Woodland/Gilgai Plain Woodland/Wetland/Riverina Plains Grassy Woodland Mosaic
Grassland	Plains Grassland
High Riverine Woodland	Riverine Grassy Woodland
	Riverine Grassy Woodland/Riverina Plains Grassy Woodland Complex
Pine	Pine Box Woodland/Riverina Plains Grassy Woodland Mosaic
	Pine Box Woodland
Plains Grassy Woodland	Plains Grassy Woodland
Riverine Woodland	Riverine Grassy Woodland/Riverine Sedgy Forest/Wetland Mosaic
	Riverine Grassy Woodland/Riverina Plains Grassy Woodland/Black Box Chenopod Woodland Complex
Sand Ridge	Sand Ridge Woodland
Wetland	Plains Grassy Wetland
	Red Gum Wetland
	Red Gum Wetland/Plains Grassy Wetland Mosaic
	Lagoon Wetland

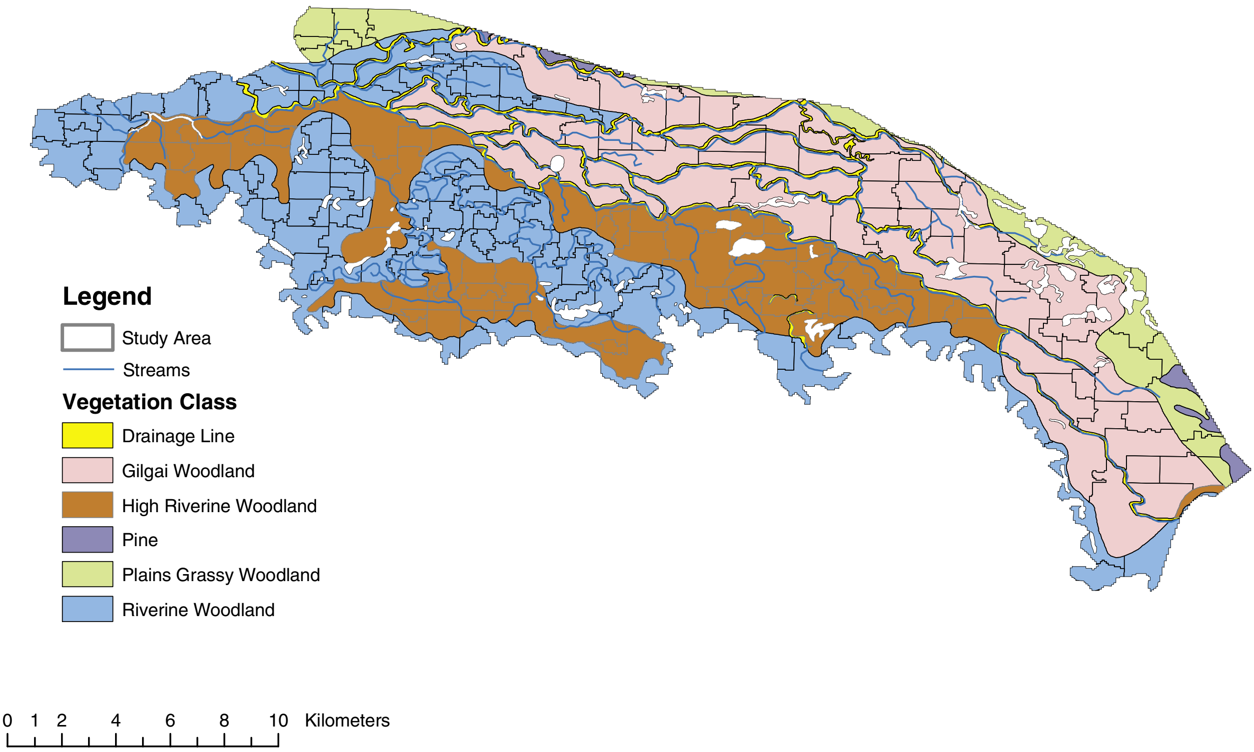
magnitude. Incorporating these data with the spatial extent and duration data provided by Water Technology we were able to generate data on the extent and duration of flood events as a time series. The primary source of vegetation information for the floodplain is the Department of Sustainability and Environment (DSE) Pre-1750 Ecological Vegetation Class (EVC) mapping at 1:100,000 scale. This was produced by interpolating limited site information with topographic mapping. Current vegetation distribution has been derived by combining the Pre-1750 map data with the DSE Tree Density data. The latter was derived by satellite interpretation. We aggregated the mapped EVC classes into simplified project vegetation classes based on position in the landscape and response to flooding regime (Table 8.1)

The dynamic spatial model required a mapped potential distribution of vegetation classes. These classes defined the endpoints for the development of native vegetation on the mapping units. In theory this long-term distribution will be determined by a combination of soil type, position in the landscape and flood regime. Because we wish to model the ecosystem services provided by the floodplain under the changed flood regime, the potential vegetation maps must be based on this regime. We modelled the Pre-1750 vegetation data using Pre-1750 flood data provided by Water Technology. In conjunction with soil and landscape data these were used to produce statistical relationships (discriminant function analysis) for the position of vegetation in the landscape. Note the vegetation classes Wetland, Sand Ridge and Drainage Line were excluded from the statistical analysis because consistent relationships could not be derived from the data available.

The statistical model produces reasonable predictions of current vegetation across the broader floodplain. At the local scale it still requires refinement and is therefore not suitable for use as an accurate predictor of future vegetation patterns. Field checking of the predictive model focused around the boundaries of mapped Pre-1750 classes. Vegetation class was evaluated on the presence of remnant species where extant, or on landscape attributes where native vegetation was absent. The classification accuracy was only 50%. Vegetation classes in order of descending classification accuracy were Plains Grassy Woodland, Grassland, Riverine Woodland, Grassy Woodland, Black Box Woodland, High Riverine Woodland and Cypress Pine.

While researchers were awaiting the development of the statistical model, PVC attributes (as derived from pre-1750 EVCs mapping) was used for input into the dynamic model, and also for the selection of mapping units. However, further refinement of the dynamic model was suspended when it became clear that the future flood regime data would not become available within the timeframe of this project. Consequently the spatial vegetation model could not be implemented and was in the short term no longer required.

Figure 8.2 Mapping units and aggregated vegetation classes for the floodplain study area



8.2.3 Creation of map base

The spatial basis of the dynamic model is approximately 300 mapping units. Mapping units (Figure 8.2) are chosen so that each is, as far as possible, uniform in terms of soil, vegetation and flood data. Pre-1750 vegetation and flood data were used because modelled future flood regimes did not become available during the project. Some aggregation of mapping units was required to keep run times short enough to permit interactive exploration of the model. GIS techniques were developed that ensured the integrity of the spatial pattern of the landscape during aggregation.

8.2.4 Review of vegetation responses to land management

Vegetation transition tables (e.g. Table 8.2) were constructed for each vegetation class to provide a structure for capturing expert estimates of successional changes in vegetation following proposed changes to land management regimes. The transition tables combine qualitative descriptions and quantitative estimates of changes in the dominant structural elements of each vegetation class as it progresses through predicted successional stages. We used the literature as well as input and feedback from experts and stakeholders in the catchment to complete the tables.

The description of each vegetation class at the beginning of a transition cycle was based on field observation for that vegetation class under each management regime (i.e. cropping, grazing or conservation). The structural components of the NRE Habitat Hectare score (Parkes and others 2003) were estimated for this initial state by comparison with the Ecological Vegetation Class benchmarks (Department of Natural Resources and Environment, undated a, b). These components include large trees, canopy cover, understory, recruitment, weeds, litter and logs (Bennett and others 1994).

This process was repeated for each successional phase until the vegetation class reached the benchmark condition. At this point it was assumed the vegetation was structurally stable. Estimations for each vegetation class and management combination are based on a 'typical' pattern of historical land use for the area (Bennett and others 1994; Robinson 1996; Spooner and others 2002). We note though, there may be areas of vegetation that have been subject to a land use or management regimes not typical of standard farming practices, in which case the responses estimated here may not be applicable.

The time intervals for each management phase (Table 8.3) were chosen to fit land use changes expected by the CMA. Should the proposed changes in the levees go ahead, and the floodplain is inundated more frequently, the CMA wishes to acquire all freehold land on the floodplain. Cropping and grazing would be permitted under lease during a transition period. Three year leases are likely, so multiples of three years have been used to define cropping and grazing phases. Once the land use change process moves from grazing towards conservation management, ecologically determined time categories are more appropriate as it is assumed no other management intervention occurs beyond this point.

Table 8.2 Sample transition table

Note: The Vegetation Classes are amalgamations of the Victorian Ecological Vegetation Classes — see table 8.1 and accompanying description in the text.

Vegetation Class: Plains Grassy Woodland	Benchmark: (Riverina Plains Grassy Woodland)	State	Phase 1	Phase 2	Phase 3	Response
Cropping			**0-3 months**	**6 months**	**1 year**	**1-6 years**
General description	Open woodland, shrubby understory, diverse ground layer dominated by grasses	Some widely spaced, mature remnant trees, no recruitment, no shrubs, fallen timber piled or removed, no litter, annual weeds/ pasture species prolific	Bare ground following cultivation (Some widely spaced, mature remnant trees, no recruitment, no shrubs, fallen timber piled or removed, no litter,)	Annual crop cover (Some widely spaced, mature remnant trees, no recruitment, no shrubs, fallen timber piled or removed, no litter)	Stubble cover or (Some widely spaced, mature remnant trees, no recruitment, no shrubs, fallen timber piled or removed, no litter, annual weeds/pasture species prolific)	Some widely spaced, mature remnant trees, no recruitment, no shrubs, fallen timber piled or removed, no litter, annual weeds/pasture species prolific
Large trees	>80cm 4-8 p/ha	3	3	3	3	3
Canopy cover	10%	0	0	0	0	0
Understory	95%	0	0	0	0	0
Recruitment	Non episodic	0	0	0	0	0
Weeds		0	0	0	0	0
Litter	5%	0	0	0	0	0
Logs	15m/1000m2	0	0	0	0	0
Total		3	3	3	3	3
Cropping-grazing			**<3 years**	**3-6 years**	**6-9 years**	**9+ years**
General description	Open woodland, shrubby understory, diverse ground layer dominated by grasses	Some widely spaced, mature remnant trees, no recruitment, no shrubs, fallen timber piled or removed, no litter, annual weeds/ pasture species prolific, stubble/trash cover	Stubble/trash, exotic annual cover,	Exotic annual and perennial species proliferate, some native grasses may appear	Native perennial species increase cover, some logs accumulate under remnant trees	Widely spaced mature trees, no recruitment, some native perennial grasses, some logs

Large trees	>80cm 4-8 p/ha	3	3	3	3	3
Canopy cover	10%	0	0	0	0	0
Understory	95%	0	0	0	5	5
Recruitment	Non episodic	0	0	0	0	3
Weeds		0	0	0	0	4
Litter	5%	0	0	3	3	3
Logs	15m/1000m2	0	0	0	3	3
Total	5m	3	3	6	9	21

Grazing - conservation			**0-40 years**	**40-160 years**	**160-320 years**	**320 years +**
General description	Open woodland, shrubby understory, diverse ground layer dominated by grasses and forbes	Widely spaced mature trees, no recruitment, some native perennial grasses, some logs	Widely spaced mature trees, some recruitment, some recruitment of shrubs and increased cover of native ground layer species, weeds biomass increase, increased litter and some log accumulation.	Some large trees, adequate recruitment, shrubs and increased cover of native ground layer species, decreased weed cover increased litter and log accumulation.	Large trees at natural densities, adequate recruitment, diverse shrub and native ground layer species, decreased weed cover increased litter and log accumulation.	Open woodland structure, mature vegetation, adequate regeneration, diverse and well developed, diverse shrub and grassy ground layer, large quantities of fallen timber and organic litter,
Large trees	>80cm 4-8 p/ha	3	3	5	8	10
Canopy cover	10%	0	0	0	3	5
Understory	95%	5	10	10	20	25
Recruitment	Non episodic	3	3	6	10	10
Weeds		4	7	7	15	15
Litter	5%	3	5	5	5	5
Logs	15m/1000m2	3	3	5	5	5
Total		21	31	38	66	75

Table 8.3 Time intervals of management phase changes used in vegetation transition tables

Phase	Time frame description
Cropping	Time frames based on leasing. The time categories used are based on a normal crop cycle, from cultivation, to crop/harvest and stubble/pasture back to cultivation, giving a total cycle of 1-3 years for the cropping land use.
Cropping to grazing	Time frames based on leasing. It is assumed that continual grazing is carried out under a 3 year leasing arrangement with stocking rates and grazing periods set by lease conditions and seasonal conditions.
Conservation	Time frames are based on ecological processes. It is assumed that continual grazing ceases (although this does not preclude the use of strategic grazing for ecological purposes) and that there is no other management intervention except that required to meet statutory obligations (eg.noxious weed control)

The estimates of changes in the structural components of the Habitat Hectare Score were based on field observations, Habitat Hectare assessments in similar vegetation types in Sheep Pen Creek (Section 9), and expert opinion. The literature was used to further refine predictions of changes in structural components (Bennett and others 1994; Robinson 1996; McNally and others 2000; Major and others 2001; Gibbons and Boak 2002; Robertson 2002; Spooner and others 2002).

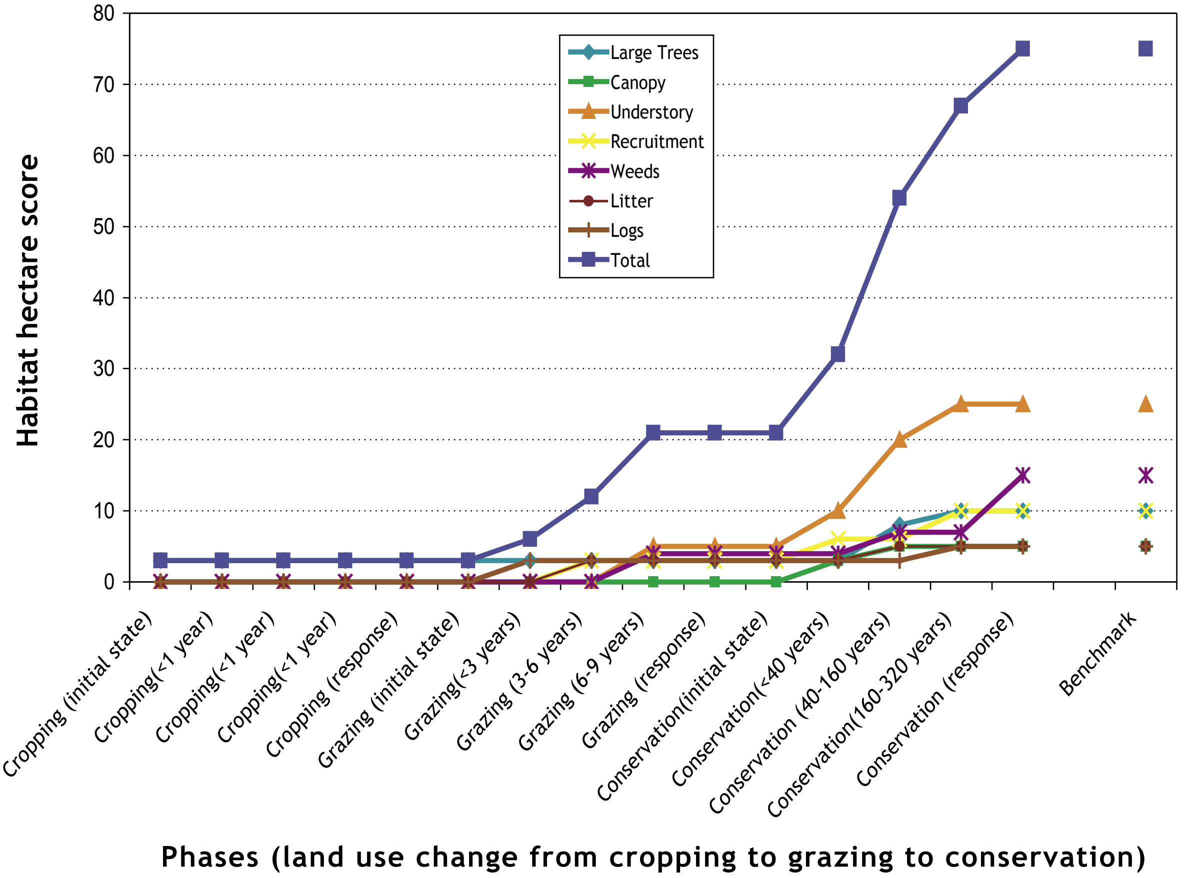
Several assumptions were made in the generation of these partial Habitat Hectare Scores. First, vegetation classes lower in the landscape profile and/or closer to streams increase their biomass faster than classes on drier, less fertile sites, but such sites are more prone to weed invasion (regularly flooded vegetation classes excluded). Second, grassy vegetation communities not subject to flooding are more susceptible to invasion by exotic annual weeds. Weedy grassy vegetation types are assumed to retain some 'weedy' elements throughout the success ional process (Berwick pers comm.; Hobbs and Yates 2000). Third, all vegetation classes (at paddock scale) retain some remnant trees regardless of current land use, scoring a minimum of 3 for "large trees". Finally, we assumed that longer time frames, the greater the probability of a disturbance, such as drought, fire or high rainfall/flooding, causing a regeneration or recruitment event.

Whilst the primary purpose of the vegetation transition tables was to define successional processes for the dynamic model, they have been a useful communication tool to illustrate changes in structural elements of the Habitat Hectare Score under various management regimes (Figure 8.3).

8.2.5 Overview of dynamic model of vegetation response to flooding and management

Future land use options and responses of ecosystem services were explored with the dynamic spatial model (Figure 8.4). It provides a systematic approach to examining the interconnected, multi-scale and dynamic nature of the ecosystem and production processes on the floodplain. The model was built as a series of views (layers) within the Vensim (Ventana Systems Incorporated 2003) simulation environment. The views consist of three types:

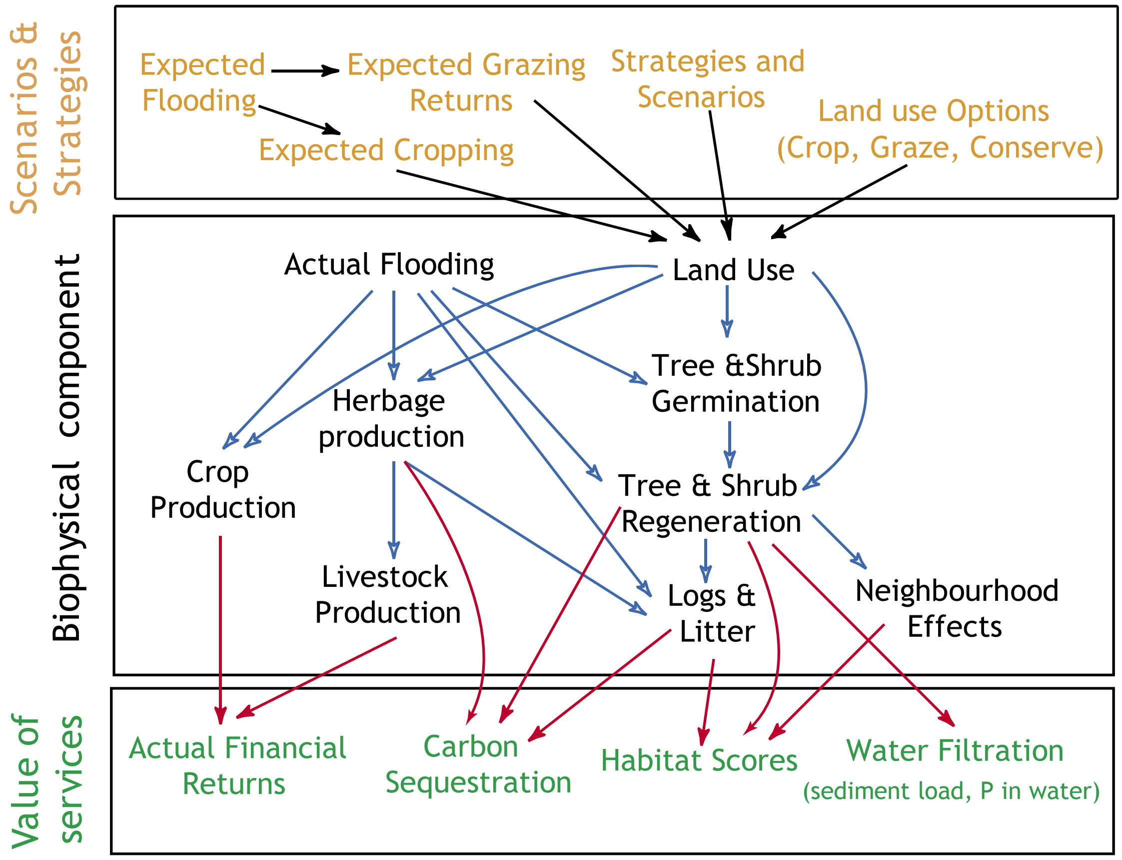
Figue 8.3 Hypothetical change in Habitat Hectare Score with regrowth of native vegetation



1. Biophysical processes — vegetation growth and crop and livestock production. They consider the impact of the current state of vegetation, land use and flooding. Key components are shown in black in Figure 8.4.
2. Ecosystem services — these calculate the quantity of the ecosystem services given the land use, flood regime and vegetation states calculated by the biophysical process modules. These components are green in Figure 8.4.
3. Scenarios and strategies — these describe the land use alternatives and management options (or decision rules) that allocate land to these uses. These are shown in orange in Figure 8.4.

The model explores how changing flooding regimes and land management decisions affect the key ecosystem services and goods of the floodplain. The present cover of woody vegetation (derived from 1999 Victorian Tree Density data) on each mapping unit, provide starting values for preliminary model runs. The simulation is in annual time steps for one hundred years. This time frame captures some of the slow dynamics of native vegetation change, and also includes the impacts of larger less frequent flood events. Currently the historical flood pattern is replayed into the future. Future versions may include flood patterns that take account of global climate change or the impacts of upstream catchment and river management on river flows.

Figure 8.4 The structure of the floodplain dynamic spatial model



8.2.6 Dynamic model — biophysical processes

The biophysical processes are modelled as herbaceous production and a woody regeneration.

Herbaceous growth is represented by annual rainfall and water use efficiency as determinants moderated by the flooding regime, grazing and competition with woody vegetation. This simple routine is adequate given the annual time step of the model.

In contrast, woody regeneration requires more complex relationships due to the long development time of woody vegetation and differential impact of grazing and flooding at different phases of development. The key determinants in the regeneration of woody vegetation on the floodplain, are:

- the frequency and extent of germination events determined by the area of a seed source;
- the flooding regime and herbaceous biomass (through competition); and
- the survival and growth of a cohort as it moves through age/size classes.

Within each mapping unit the two woody vegetation components considered are shrubs and trees. Within these components four size/age cohorts are simulated: seedlings, recruits (vegetation that is becoming established), middle aged and old woody vegetation. Shrub and tree components are crucial as they determine vegetation structure, with major consequences for the ecosystem services being evaluated, and they are affected by flooding and management.

Survival of seedlings and recruits is a function of the animal stocking rate and flood regime. Literature (Jacobs 1955; Bren and Gibbs 1986; Chesterfield 1986; Bren 1987, 1991, 1992; Minson and McDonald 1987; Heinrich 1990; Cuddy and others 1993) and expert knowledge from stakeholders and local researchers, in addition to that collated in the vegetation transition tables (sample Table 8.2), aided the development of quantitative relationships. The rate at which woody vegetation moves through the age/size classes is determined by the innate growth rates of the vegetation type considered and the management regime. For example, Red Gum recruits (saplings) tend to form long-standing thickets because they germinate in patches in large numbers, and are poor 'self thinners' (Chesterfield 1986). Natural thinning takes a long time and there is slow diameter growth (Jacobs 1955). Artificial thinning can increase the growth rate and allow the remaining trees to reach the next size class quicker. In the model we explore this by altering the time trees remain in the establishing age class under different management regimes.

The biomass of the woody vegetation is calculated as a cumulative increase per unit area per year depending upon the vegetation type, the age/size class, mapping unit characteristics, the biomass that enters the woody litter pool and the aging process. Woody vegetation in the seedling age/size class is assumed not to contribute to the total biomass pool. It is also assumed that the old age class is not accruing biomass except through the movement of middle aged biomass into the old age/size class. In the tree and shrub recruit, middle aged and old age/size classes a proportion of biomass is assumed to contribute to the fine litter pool (leaves/bark/small twigs) with the addition of those shrubs 'dying' in the old age class. Decay rates of 2 years are set for fine litter (Glazebrook and Robertson 1999). For the old age/size class the tree biomass that is removed from the living pool by mortality is added to the coarse woody litter pool as logs with decay rates determined from literature summarised by Mackensen and Bauhus (1999). Decay rates are influenced by moisture content (Mackensen and Bauhus 1999) so in years that are flooded these decay rates are increased. The current biomass of coarse woody debri on wooded areas on the floodplain has been estimated in other studies (MacNally 2000). Therefore, for model runs starting values for each land unit were calculated by adjusting the coarse woody debri estimated for the wooded area by the unwooded area. Key outputs from these modules are area and biomass of woody vegetation in the various age / size classes and structural groups, biomass of logs and litter and the pasture biomass. They are inputs to the ecosystem service evaluation and management decision modules.

8.2.7 Dynamic model — implementing management scenarios

Before running the model, land management scenarios were defined in two steps. First, the attributes of four land use alternatives (cropping and grazing rotation, commercial grazing, mixed use: grazing and conservation, conservation) were specified for each mapping unit. The key attributes of the land use alternatives that can be changed are the frequency of cropping, the percentage of herbage utilised by grazing (and therefore the stocking rate), and the strategy for grazing in areas designed for mixed conservation and grazing. Activities that could be added include timber harvesting, and active conservation measures such as planting, seeding and artificial thinning.

The second step before running the model is to specify the management strategy that determines what land use alternatives are selected for each mapping unit. The management strategy is constant for the duration of each run, however the decisions implied by each strategy are made annually, therefore the choice of land use on a particular mapping unit may change during a run. Management strategies can be based on the expected financial return from each land use alternative, and the state of native vegetation on the mapping unit. Four alternative strategies are currently defined: maximise financial returns from the floodplain; maximise conservation value; protect a certain percentage of the best condition vegetation of the different types; or used mixed land uses to achieve multiple goals.

8.2.8 Dynamic model — evaluating uncertainty

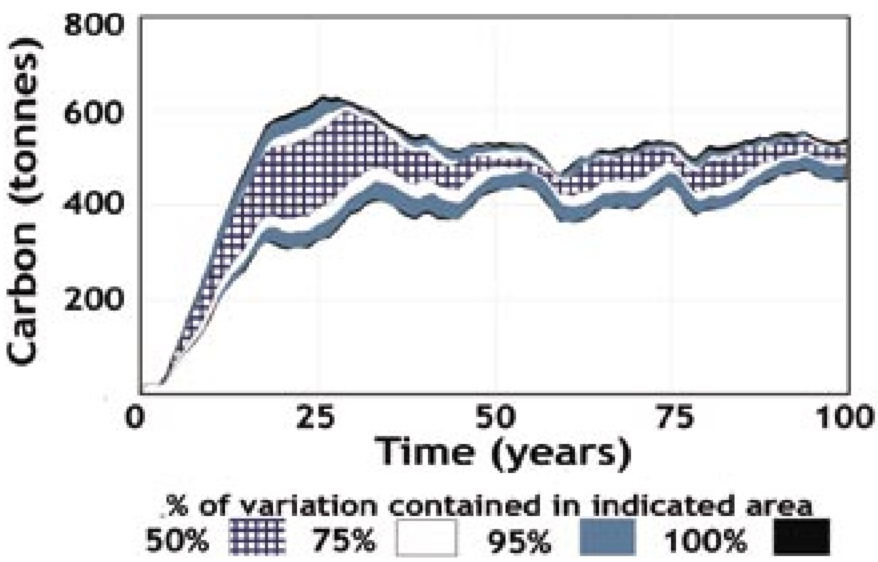
In Section 4 we stated that understanding ecosystem behaviour is fundamental to the establishment of effective market, incentive and regulatory schemes for sustainable use of ecosystem services, not only because of it underpins economic valuation, but also because of risk and uncertainty. All social-ecological systems contain risk and uncertainty. For example, a key management variable identified in the scenarios workshop was grazing. We conducted a sensitivity analysis of the impact of the intensity of livestock grazing (pasture utilisation) on the carbon store across a mapping unit using surrogate data for the current flooding regime (Figure 8.5). This analysis indicates that the largest variation in carbon sequestration due to grazing management occurs over the medium term (20 to 30 years) with variability diminishing over the longer term.

8.2.9 Evaluating changes in ecosystems services

Regulation of climate is evaluated in the model as the amount of carbon sequestered by native vegetation. Total biomass (woody and herbaceous) is converted to carbon by applying a carbon factor which estimates the proportion of dry biomass that is carbon. Generally biomass is made up of approximately 50% carbon (carbon factor = 0.5), although this figure will vary slightly in different components of the tree and litter (Australian Greenhouse Office 2002).

Maintenance and regeneration of habitat was evaluated in the model with an index based on the structural components of the Habitat Hectare approach (Parkes and others 2003). Structural measurements were approximated using modelled output. We defined vegetation quality as the degree to

Figure 8.5 Sensitivity analysis of the effect of grazing intensity on the carbon store



Note: Percent utilisation of herbage ranging between no grazing (0%) and a moderate-high grazing level (50%).
The shaded areas indicate the space within which 50%, 75%, 95% and 100% of the predictions of the carbon store fell.

which the modelled vegetation differs from a benchmark (Section 8.2.4). Benchmark represents the assumed average characteristics of a mature stand of the same vegetation class immediately prior to European settlement (i.e. 1750). Use of this benchmark does not imply that the goal of management should be to restore all vegetation to its 1750 state, but rather it is to provide a consistent reference point against which loss and gains of habitat quality can be measured. Each mapping unit ('habitat') is therefore given a 'Habitat Score' by comparing model output to the benchmark. Benchmark data were transformed to be comparable to model output. Multiplying the 'Habitat Score' by the area of the mapping unit gives a quality-quantity measure. The components and weightings of the 'Habitat Score' and data requirements are shown in Table 8.4, which shows the differences between the scoring system used in this case study and the NRE approach. Those components that are assessed at the site scale, or in our case the mapping unit scale, are structure and species composition, but our model could not account for species composition, including weediness. In our model spatial components are estimated by analyses of woody area and biomass in adjacent mapping units.

Table 8.4 Components, weighting, and data requirements for the habitat score (HS) as used by the NRE Habitat Hectare assessment compared to that used in the model

Scale	Component	NRE HS data requirement	Score	Modified HS data requirement	Score
Site	Large Trees	Tree Density by DBH & health	10	Area /biomass of old trees	10
	Tree (canopy) Cover	% cover, mature height & health	5	Area/biomass of establishing, middle aged and old trees	5
	Understorey (non tree) strata	Presence/absence & Diversity/cover of life forms	25	- Shrub biomass and area by age classes - Grass biomass	5 5
	Weediness	Weed cover, threat	15	x	NA
	Recruitment	Evidence recruitment	10	Area establishing and 'dying' vegetation	10
	Organic Litter	% cover	5	Litter biomass	5
	Logs	Number, diameter	5	Log biomass	5
Landscape	Patch Size	Area, disturbance	10	Current and adjacent LUs woody area & biomass	8
	Neighbourhood	% native veg in 100m, 1km and 5km radius	10	% woody area and biomass in LUs within 5kms radius	10
	Distance to core area	Distance to patch >50 km	5	x	NA
		Max habitat condition score	100		63

Note: x = not assessed.

8.2.10 Filtration and sedimentation

Evaluation of water filtration and erosion control are not yet implemented. The intention is to estimate changes in sediment loads of water leaving the floodplain. Calculation of these could not be completed because it is dependent on the flooding scenarios , which are not yet available (see discussion under collection and development of core datasets — Section 8.2.2). Analysis will be undertaken outside the dynamic model using digital terrain analysis, vegetation cover outputs from the dynamic model and predicted flood characteristics for a range of flood scenarios. Outputs would include:

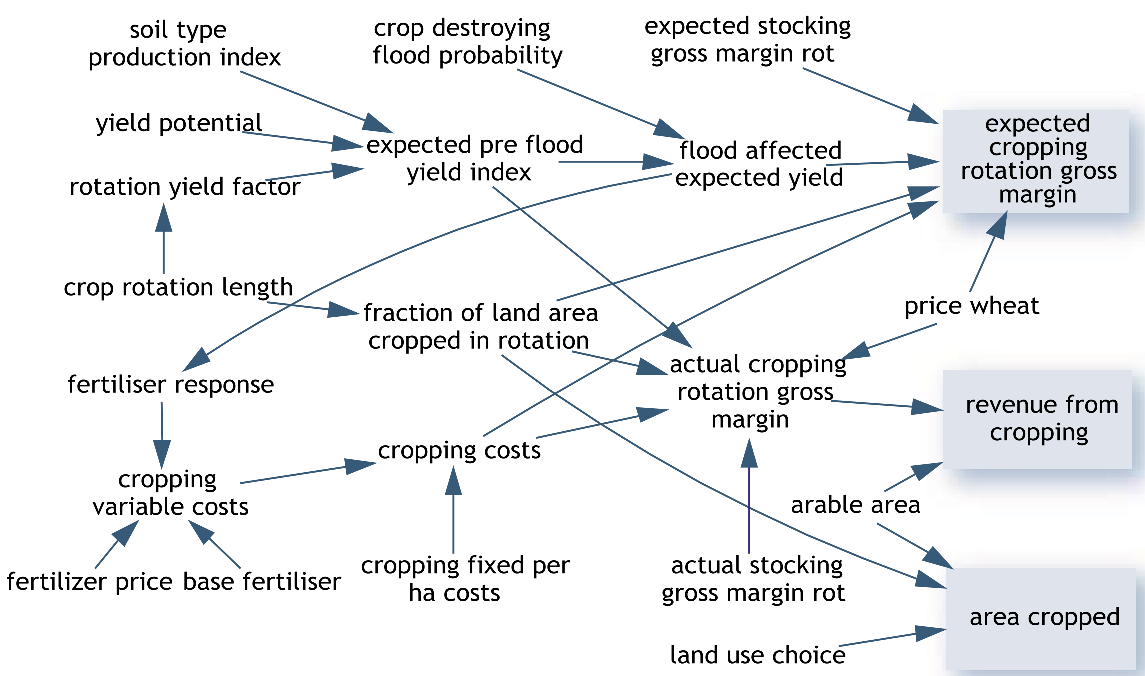
- assessment of how changes in floodplain vegetation would affect sediment and phosphorus deposition on the floodplain;
- assessment of the likely changes in sediment and phosphorus loads for floods of varying magnitudes;
- a review of water quality data;
- assessment of the likely affects on channel bank erosion of changes in flow confinement in the channel; and
- assessment of critical knowledge gaps.

8.2.11 Evaluating the socio-economic consequences of management scenarios

To approximate economic trade-offs involved in changed land use we estimate actual and expected net financial returns from using the land for cropping, cropping rotations or grazing. Actual returns take into account the impact of the flood events in a specific year on production, while expected returns calculate the expected impact of floods on financial returns based on historical averages of flood activity. Comparisons of expected returns are used as the basis of land use decisions, while aggregated actual returns are reported as the financial value of agricultural activity on the floodplain.

For cropping and crop rotations estimates of net financial returns are based on estimates of yields, variable costs, and attributable fixed costs. Potential crop yield are defined as the highest likely yield from an area of land in a flood free year. Potential yields take into account soil type and the effects of rotations. Actual yields takes into account the impact of

Figure 8.6 Calculating expected and actual returns from cropping rotations on the floodplain



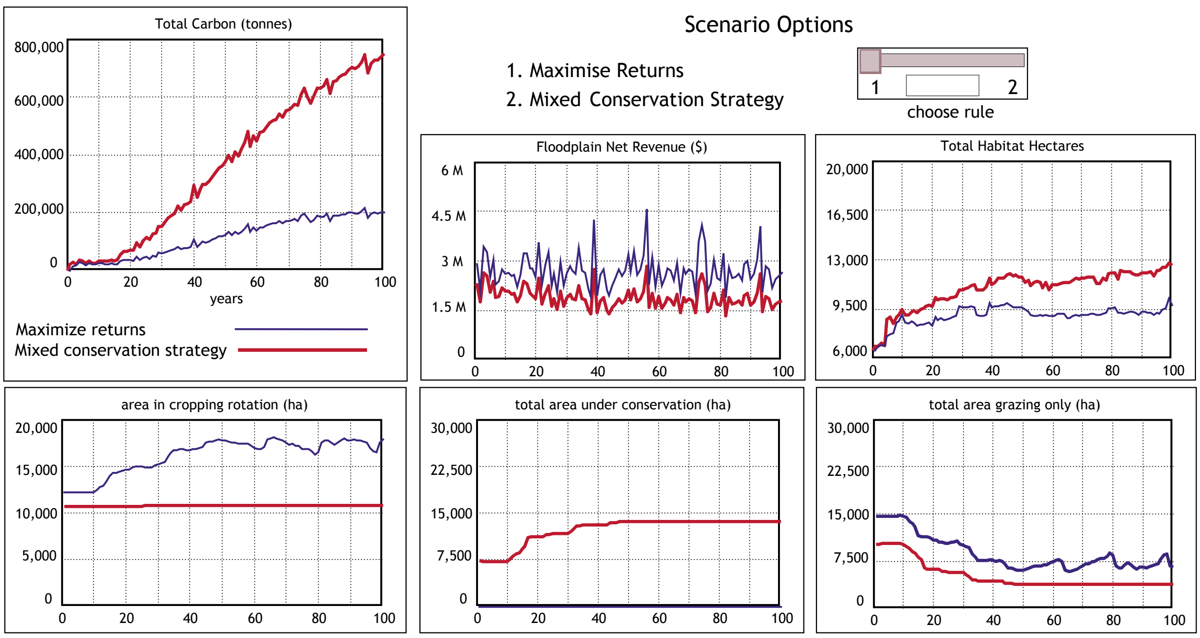
flooding in any given year. Expected yield takes into account the expected impact of flooding on crop yield. An overview of the returns from cropping calculations are shown in Figure 8.6. The capacity for farmers to reduce variable inputs as a function of expected yields is also included.

Estimates of net financial returns from grazing are based on returns to cattle agistment, and are calculated as rate per head of cattle agisted multiplied by the stocking rate. Livestock managers are assumed to manage stocking rates on each mapping unit to utilise a specified percentage of the available herbage. Expected returns from stocking rates take account of the impact of flooding on herbage production, and the consequent change in stocking rates. Flooding is assumed to decrease pasture production due to submersion. The percentage herbage utilisation (PHU) varies with the land use alternative. For cropping and commercial grazing PHU is set to approximately 70%. This is assumed to be heavy enough to prevent regeneration of tree seedlings. Grazing is excluded from the conservation land use alternative. A mixed use strategy excludes grazing for a period of time after a (flood triggered) germination event. After this a lighter grazing regime is applied. Variations on this decision rule are permitted.

8.3 Interactions and trade-offs among ecosystem services

Our review of literature and discussion with experts from the catchment have revealed that knowledge of the floodplain ecosystem, ecosystem services, underlying biophysical processes and the interactions between them is far from complete. An alternative to seeking complete knowledge is to identify the critical components only. The model is constructed to evaluate the ecosystem services under the range of management options for the floodplain that are being considered. The primary output of the model is a set of graphs that track the key ecosystem services levels and values over a one hundred year time frame

Figure 8.7 Land use and ecosystem services under two management options



under different management options. An example of this from the current version of the model is shown in Figure 8.7.

The graphs are designed to show the impact of management options on all modelled ecosystem services in relation to the trends and variation in the system and allow the user to explore the tradeoffs among the ecosystem services being considered. In the model management options specify decision rules for allocating different mapping units to land uses on the basis of their characteristics. The bottom three graphs of Figure 8.7 show how management strategies affect the pattern of land use.

8.4 Conclusions and lessons learned

As has already been observed in the dairy enterprise case study, a key problem in undertaking such system analyses is integrating data of variable quality and reconciling good understanding of some processes with poor understanding of others. The approaches taken here however, have been useful for integrating what is known and is a good basis for exploring tradeoffs between ecosystem services both within and between scenarios. When flood data become available the simulation model can be refined, and it is expected that it will be a useful contribution when considering future floodplain management options that take account of ecosystem services.

9 Ecosystem services from a dryland sub-catchment

9 Ecosystem services from a dryland sub-catchment.

Collaborators: Art Langston, Paul Ryan, Jenny Langridge, Nick Abel, Roel Plant, John Ive

The aim of the case study is to evaluate the impact of changes in vegetation patterns on ecosystem services in the Sheep Pen Creek sub-catchment.

9.0 Case study highlights

Project outputs include:

- estimates of changes in the flow of ecosystem services as the cover of native vegetation increases;
- a table of ecosystem service indicators and their quantitative relationships with the variables they depend on;
- GIS algorithms for calculating the spatial components of Habitat Hectare Scores;
- GIS algorithms for calculation of shade and shelter which could be adopted to other ecological assessments such as seed fall;
- a modelled map of current vegetation in Sheep Pen Creek Catchment;
- a table of decision rules for determining the most suitable locations for planting native vegetation to enhance biodiversity;
- a grouping of these decision rules and aggregation of associated weights into socially relevant categories;
- maps of the suitability for native vegetation planting across the landscape; and
- maps of the options for future native vegetation enhancement at a range of cover targets.

Key observations from workshops and analyses are that:

- potentially 164,000 T of carbon could be sequestered if the entire catchment was covered by native vegetation compared to 34,000 T at a 15% native vegetation cover target and 66,000 T at a 40% target (ecosystem service: "regulation of climate");
- gains in the spatial habitat value of native vegetation per unit area re-vegetated increase above a 30–40% native vegetation cover target (ecosystem service: "maintenance and regeneration of habitat");
- the benefit from shelter belts peaks at 40% native vegetation cover target (ecosystem service: "provision of shade and shelter");
- erosion rates are much lower under native vegetation compared with agricultural vegetation types (ecosystem service: "water filtration and erosion control");
- reductions in bank erosion increase more rapidly in the lower reaches of the sub-catchment under increasing native vegetation cover, however this only represents 3% of the total length of creeks (ecosystem service: "water filtration and erosion control");
- yield to channel reduces more rapidly than loss to deep drainage as native vegetation cover increases (ecosystem service: "regulation of river flows");
- water yield to channel is slightly affected by the spatial configuration of vegetation (ecosystem service: "regulation of river flows and ground water"); and
- water yield to deep drainage is sensitive to the area of deep rooted perennials (ecosystem service: "regulation of river flows and ground water").

Key considerations are that

- many service indicators cannot or should not be expressed as dollar values;
- agricultural vegetation types do provide some ecosystem services but their contribution is relatively small compared with native vegetation;
- the ecosystem services 'maintenance and regeneration of habitat'; 'provision of shade and shelter'; 'water filtration and erosion control'; maintaining healthy waterways; and to a lesser degree 'regulation of ground water and river flows' are all dependent on the spatial arrangement of native vegetation in the landscape;
- some ecosystem services show thresholds and non-linear responses as native vegetation cover increases; planning for these thresholds will affect the returns to investment in revegetation;
- because gains in the spatial habitat value of native vegetation per unit area increase above a 30–40% native vegetation cover targets, it is better to concentrate funds for revegetation in several small areas rather than disperse it across the landscape;
- relatively simple methods such as the ones used in this case study are more transparent than complex integrated assessments, and they can be built relatively quickly for particular places and problems;
- scenarios are an effective way of setting the scope for analysing ecosystem services; and
- expert opinion gave a high weight to the set of biodiversity decision rules that affect the adequacy of a pattern of native vegetation in providing habitat for native species in the presence of threatening processes. Less weight was given to rules affecting pre-settlement distributions, the representation of variation within Ecological Vegetation Classes, and social imperatives such as the conservation of rare and threatened species.

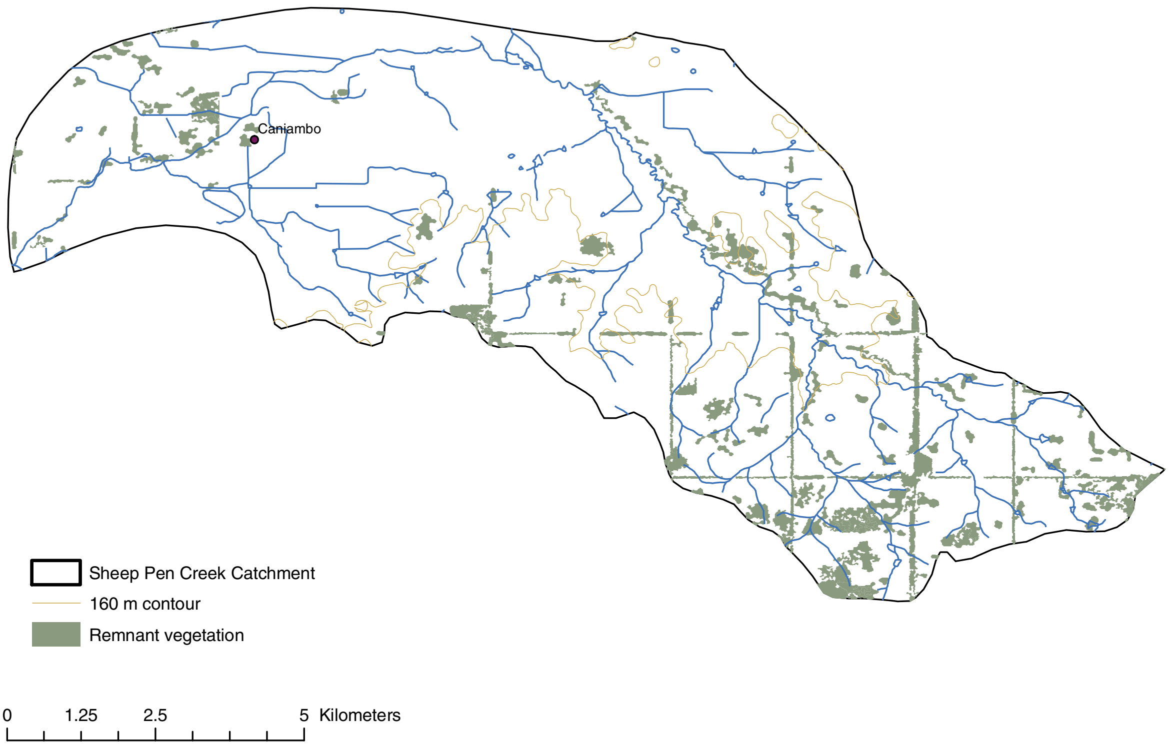
9.1 Background and Issues

This case study focuses on the delivery of ecosystem services in the Sheep Pen Creek sub-catchment (Figure 6.1). This scale was chosen because policy-making, planning and management by State agencies, Catchment Management Authorities and Landcare groups is implemented in sub-catchments. However, the biophysical processes that underpin ecosystems services dominantly occur at the landscape scale or less. Accordingly the effects flowing from these processes are aggregated to provide the sub-catchment context.

Choice of Sheep Pen Creek as the focal sub-catchment was influenced by four factors. First, dryland agriculture is a dominant land use across the Goulburn-Broken Catchment and is also the dominant land use within Sheep Pen with grazing of native pastures occurring on the higher slopes (above 160m ASL — Figure 9.1) and cropping occurring on the lower slopes in favourable years. Second, there is only one minor town within the sub-catchment (Caniambo) allowing evaluation of impacts on services associated with vegetation change without having to adjust for any effects that might be associated with a large urban area. Third, Sheep Pen is also a focus area for the Heartlands Project (http://www.clw.csiro.au/heartlands/) that is developing options for future land use and vegetation management with the catchment community. Co-locating the studies has enabled significant data and knowledge sharing between projects. Last, there is extensive knowledge and data from previous natural resource studies in this area.

Many of the biophysical attributes of Sheep Pen are typical of the mid-catchment dryland areas of the Goulburn-Broken. Annual rainfall varies across the sub-catchment from 525mm in the north-west to 600 mm in the south-east. Topography varies from 130m to 190m (60m relief) with a maximum slope of less than six degrees. The sub-catchment is drained to the north-east by Sheep Pen Creek, and then into Irish Creek through a drainage

Figure 9.1 Remnant vegetation and topographic zones in Sheep Pen Creek sub-catchment



channel. Recent research using bore data, airborne radiometric and electromagnetic remote sensing indicates that water tables are strongly influenced by a regional ground water system fluctuating in response to localised highly weathered geological formations which contribute local concentrations of salt to the ground water.

Remnant vegetation covers approximately eight percent of the Sheep Pen sub-catchment. Much of the vegetation in the higher slopes to the south-east of Sheep Pen occurs close to remnants on the adjacent hills outside the sub-catchment, thus providing some habitat connectivity. To the north more extensive remnants occur along the Broken River, however connectivity with these remnants is poor with remnants separated by up to two kilometres.

Like many sub-catchments throughout south-eastern Australia Sheep Pen has experienced a shift from traditional agriculture towards more diverse land uses. In part this is driven by declining terms of trade. As well, interest in 'lifestyle' farming, due to the sub-catchment's proximity to Melbourne and the large regional centres of Benalla and Shepparton, has increased land prices to levels that cannot be supported by traditional agricultural pursuits (Curtis and others 2000, Goulburn Broken Catchment Management Authority 2002). Despite these social changes there has been a long and continuing history of community involvement in natural resource management, with the Sheep Pen creek Landcare group one the earliest established in Australia. Salinity and erosion control, water quality issues, declining biodiversity and soil health are seen as major threats in the sub-catchment. The local community is very active in undertaking on-ground works to address these issues, in partnership with the catchment authority and state agencies. These factors provide a unique opportunity for land use and land management change in the immediate future. Information from this case study will be valuable in guiding those changes.

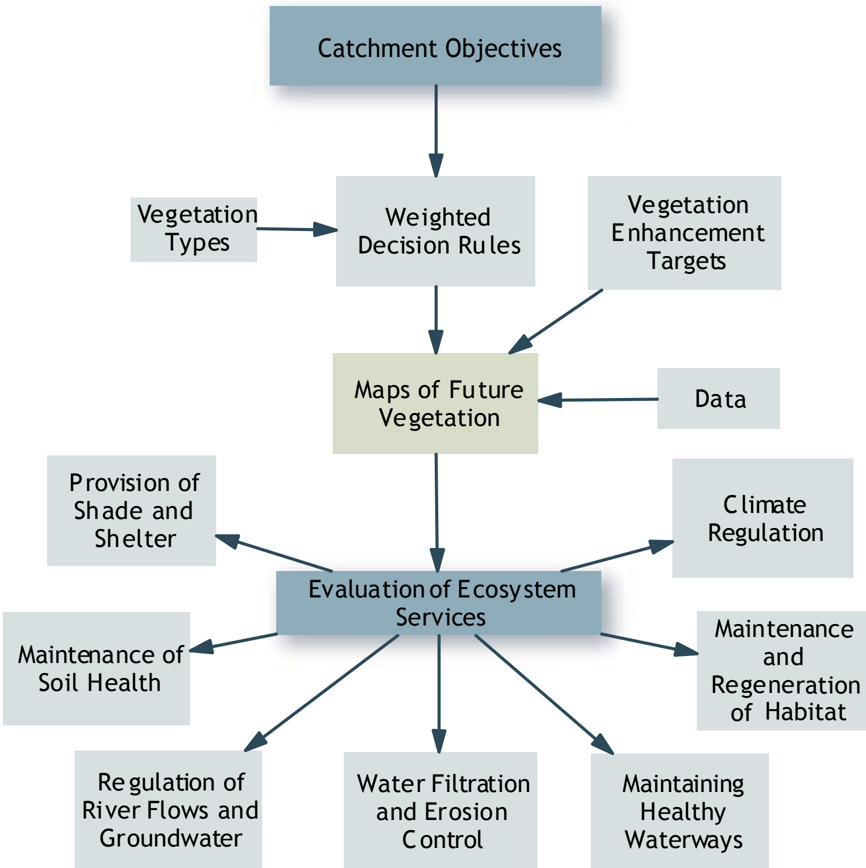
9.2 Methods and outputs

9.2.1 Overview

The case study has two major phases (Figure 9.2). First a scenario development phase draws on Catchment Management Authority objectives and State policies for the conservation of plants and animals to create maps of future vegetation enhancement options using a range of areal vegetation targets. Areal targets are defined as increases in the cover of native vegetation types from their current level in proportion to their presumed 1750 distributions. Secondly, these options are evaluated for their impacts on ecosystems services.

As with the other case studies in this project, these methods and results are presented as proof of concept. Selection of tools and choice of metrics for evaluation is largely pragmatic and combines spatial and simulation modelling, empirical relationships and expert knowledge. The objective is not to provide a definitive analysis of any one ecosystem service. Rather the case study seeks to integrate a range of evaluation and scenario building techniques to provide a tool set that is relevant for this particular case study. Application to another case study could use the same analytical framework (Figure 9.2) but the analysis tool set should be chosen to suit the biophysical attributes of the study area, the services relevant to the local community and the data available.

Figure 9.2 Case study analytical framework



9.2.2 Scenario definition

Four scenarios for defining future vegetation options were initially adopted, each guided by catchment objectives identified in the Catchment Management Authority and Department of Sustainability and Environment documents listed below. They are: biodiversity enhancement; salinity control, agricultural production and carbon storage. In this case study we evaluate ecosystem services produced in the biodiversity enhancement scenario. Evaluating ecosystem services in the other scenarios will be carried out in conjunction with the CSIRO Heartlands Project. The objectives of each scenario is outlined below.

Biodiversity enhancement scenario

Catchment Objectives:

- maintain the extent of all Ecological Vegetation Classes (EVC) at 1999 levels, with no net loss to clearing;
- build on the existing pattern of vegetation by planting and managing endemic species;
- manage 90 % of native vegetation cover according to best management practices by 2010;
- increase the cover of endangered and vulnerable EVCs to at least 15% of their pre-European cover by 2030;
- enhance connectivity and integrity through use of 'stepping stones', corridors, buffers and other linear plantings;
- provide for the habitat requirements of Victorian rare or threatened species; and
- enhance existing remnants and proposed plantings in terms of their size, shape, connectivity, and adjacency to similar remnants or plantings.

Source documents for catchment objectives:

Draft Goulburn Broken regional catchment strategy (Goulburn Broken Catchment Management Authority 2003); Draft Goulburn Broken native vegetation management strategy (Goulburn Broken Catchment Management Authority 1999); Biodiversity action planning draft strategic overview for the Victorian riverina bioregion (Ahern and others 2002a); Biodiversity action planning draft strategic overview for the northern inland slopes bioregion (Ahern and others 2002b); Biodiversity action planning draft landscape plan for the south central woodlands area — Violet Town zone (Ahern and others 2002c)

Salinity control scenario

Catchment objectives:

- control land degradation and protect important terrestrial ecosystems, productive farmland, cultural heritage and built infrastructure; and
- maintain water quality within community agreed limits for agricultural, environmental, urban, industrial and recreational uses.

Source documents for catchment objectives:

Draft Goulburn Broken regional catchment strategy (Goulburn Broken Catchment Management Authority 2003); Draft Goulburn Broken dryland salinity management plan (Goulburn Broken Catchment Management Authority 2002)

Agricultural production scenario (including livestock, crops and forestry)

Catchment objectives:

- maximise the growth rates (mean annual increment) of forestry;
- generate positive effects of shade and shelter from farm forestry on crop and livestock production;
- maximise livestock production per unit area; and
- Maximise crop production per unit area.

Source documents for catchment objectives:

Draft Goulburn Broken regional catchment strategy (Goulburn Broken Catchment Management Authority 2003)

Carbon storage scenario

Catchment Objectives:

- maintain the current extent of remnant woody vegetation;

- extending the area of permanent woody vegetation communities consistent with existing catchment vegetation management plans but with emphasis on vegetation communities with a high basal diameter and fast growth rates;
- maintain the current extent of forestry activities which use non endemic species; and
- extend the area used for plantation forestry using species with high carbon accumulation rates; produce timber that is relatively durable; and that meets the commercial criteria proposed for farm forestry; and is consistent with existing catchment vegetation management plans.

Source documents for catchment objectives:

Victorian greenhouse strategy (Department of Natural Resources and Environment 2002a); Draft Goulburn Broken regional catchment strategy (Goulburn Broken Catchment Management Authority 2003); Draft Goulburn Broken native vegetation management strategy (Goulburn Broken Catchment Management Authority 1999)

9.2.3 Mapping units, spatial resolution and time horizon

Key questions affecting methods were the choice of spatial resolution and mapping unit size; what GIS data model to use (vector or raster); the time horizon of the analysis and whether to consider vegetation condition in the analysis.

An initial decision was made to map vegetation types rather than land uses. The two are sometimes the same, but the conceptual difference is that a land use is defined by its human purpose (e.g. production of food or fibre, provision of aesthetic pleasure), whereas vegetation type more directly relates to the functional processes that deliver ecosystem services (e.g. regulation of deep drainage, storage of carbon, provision of habitat for native biota).

The next decision was the resolution at which to map the vegetation types and also the type of data to use. Considerations in determining the resolution of mapping are the processing and memory capacities of a personal computer versus the size and distributions of landscape attributes such as vegetation remnants, soils and topography. A spatial resolution of one hectare fitted the requirements of the sub-catchment. A further advantage of this resolution is that it allowed us to map incremental changes in vegetation cover and type, and show corresponding changes in the vegetation pattern, which we could not do at a coarser resolution. The need to model and evaluate the influence of vegetation pattern on ecosystem services demanded the use of a grid data model, as GIS software more easily extracts spatial statistics from grid data compared to polygon data.

In estimating the habitat value of each vegetation option we made simplifying assumptions because of difficulty in estimating the future structural habitat value of plantings, and lack of survey information on current habitat value of remnants.

The Habitat Hectares score for native vegetation types in Victoria is based on two sets of components (Department of Natural Resources and Environment undated a and b). One is based on the size of a patch of remnant vegetation and its relationship with neighbouring patches — we discuss this set below. The other set is derived from the structure and species composition of the patch compared with the Habitat Hectares benchmark condition, which is based on the assumed structure and species composition of the vegetation type before settlement. It could take hundreds of years for a newly planted patch to achieve benchmark condition from a bare state, but there is insufficient information on which to base estimates of the trajectory and rate of increase of Habitat Hectares score.

Given the lack of information on current Habitat Hectares score, and estimates of its future trajectory, we made two simplifications in modelling and mapping the vegetation targets. First, we only used the remnant size and spatial configuration component of the Habitat Hectares score to estimate the current and future habitat value of vegetation patterns. Second, we regarded all additions to the current pattern of native vegetation as if they could instantaneously play a full role in increasing the effective size of remnants and connections among them. Even if the rates of change in Habitat Hectares score, from first planting to benchmark, were known for each native vegetation type, to account for changes in structure and species composition it would have been necessary to build a complex spatial-dynamic model that captured planting dates on multiple sites in all vegetation types. Such a model is orders of magnitude more time and resource consuming than the approach we took.

The native vegetation classification we used is based on Victorian Ecological Vegetation Classes (EVCs). The primary source of information on EVCs for Sheep Pen Creek is the Department of Sustainability and Environment's (DSE) Pre-1750 EVC mapping at 1:100,000 scale. This was produced by interpolating limited site information with topographic mapping. Current vegetation distribution was derived by clipping the Pre-1750 map data with DSE Tree Density data. We aggregated the mapped EVC classes into 'Project Vegetation Classes' (PVCs) based on position in the landscape (Table 9.1). Three agricultural vegetation types were used. "Cropping rotation" includes annual crops such as canola, wheat, oats barley, field peas, lupins, and other oil seeds in rotation with other exotics. "Exotic perennial pasture" includes deep rooted, perennial species such as lucerne and phalaris. "Native perennial pasture" is dominated by native species.

9.2.4 Scenario implementation

The maps of future vegetation options were generated using Multi-criteria Evaluation (MCE). A set of weighted rules was applied to land attribute data to produce preference maps for each vegetation type. The preference maps show the relative suitability of the landscape for growing vegetation in accordance with catchment objectives (Section 9.2.2). The MCE was implemented using IDRISI® raster GIS software. Each decision rule was weighted by its relative importance to the decision process. The preference maps were then combined so that the vegetation class with the highest suitability (in terms of the decision rules) in each mapping unit was allocated for that mapping unit.

Twelve re-vegetation cover targets were used to generate mapped vegetation enhancement options for each scenario. These were: equivalent to current remnants in the catchment (8%); typical of a socially acceptable compromise between conservation and production (15%); and a set of options with targets increasing in 10% increments from 10% to 100%. The last set investigated occurrences of irregular responses to changes in native vegetation. Non-linear irregularities might be expected because the decision rules lead to non-random placement of vegetation in the landscape. The resulting spatial interaction is likely to generate the irregular responses.

Table 9.1 Relationship between vegetation classes used in this study and Victorian Ecological Vegetation Classes

Project Vegetation Class (PVC)	Victorian Ecological Vegetation Class (EVC)
Alluvial Terraces	Alluvial Terraces Herb-rich Woodland
	Alluvial Terraces Herb-rich Woodland/ Creekline Grassy Woodland Mosaic
Box Ironbark Forest	Box Ironbark Forest
	Broombush Mallee
	Heathy Dry Forest
Creeklines	Creekline Grassy Woodland
Gilgai	Gilgai Plain Woodland/Wetland Mosaic
Grassy woodland	Grassy Woodland
	Low Rises Grassy Woodland/ Alluvial Terraces Herb-rich Woodland Mosaic
Plains Grassy Woodland	Plains Grassy Woodland
Wetland	Red Gum Wetland
	Red Gum Wetland/Plains Grassy Wetland Mosaic
	Wetland Formation

9.2.5 Definition of decision rules and rule weights for biodiversity enhancement scenario

Eighteen decision rules (Table 9.2) were created based on catchment objectives, ecological theory and design principles adopted for the CSIRO Heartlands Project. The rules are used to create a pattern of vegetation options that would enhance biodiversity outcomes in the sub-catchment. Each of these decision rules was weighted (multiplied by an index of priority) to reflect the relative influence of each rule on the desired vegetation pattern. This weighting process requires both expert and community opinion to fully embrace the range of views about how vegetation enhancement should be achieved. Time constraints limited our analysis to in-house expert opinion.

Rather than define the weights directly we adopted a process of pair wise comparison of the relative importance between any two decision rules. The technique is described by Saaty (1977). These pair wise comparisons were evaluated through an ordination that generated weights that best satisfied the pair wise comparisons. Weights across all decision rules sum to one.

Table 9.2 Scenario decision rules for the biodiversity enhancement scenario with the associated rationale

Rule No	Rule	Rationale
Rule 1	Commit remnants on public land to their 1750 PVC.	Retention of current remnants is seen as a non-negotiable priority. Often public land is the only place where native vegetation persists, and public tenure can provide security against clearing and/ or hostile management.
Rule 2	Commit remnants on private land to their 1750 PVC.	Retention of current remnants is seen as a non-negotiable strategy to enhance biodiversity. Private land has usually targeted the more productive land within the landscape, therefore private remnants may be the only source of PVCs whose range is restricted to more productive land of the landscape.
Rule 3	Exclude areas physically or socially inappropriate for vegetation.	Investment of capital and associated landscape modification may preclude any realistic or acceptable restitution for biodiversity purposes. Likewise some areas may hold inherent cultural significance that is inconsistent with management for biodiversity. Further some area might be biologically unsuitable for vegetation such as dams or lakes or urban areas.
Rule 4	As far as possible allocate cleared areas to their 1750 PVC.	State policy is to revegetate cleared land to its original Ecological Vegetation Class, thus contributing to the comprehensiveness criterion of effective and efficient nature conservation policy. An additional rationale is that natural regeneration is the cheapest and most effective means of revegetation provided the seed bank for the complement of native species has not be exhausted and previous land use has not irrevocably changed conditions to the extent that germination and successful establishment are not practical. Consequently this guideline seeks to identify areas were natural regeneration is most likely to be successful for each PVC type.
Rule 5	Not used	The original rule focused on ensuring heterogeneity of landscape elements. As this is essentially similar to rule 7 the two were integrated. Rule sequence numbers have been maintained because of methodological requirements.
Rule 6	Not used	The original rule focused on ensuring heterogeneity of landscape elements. As this is essentially similar to rule 7 the two were integrated. Rule sequence numbers have been maintained because of methodological requirements.
Rule 7	As far as possible allocate geographically dispersed areas to their 1750 PVC.	A geographically dispersed representation provides insurance against threatening processes impacting upon a single site and also provides subtle variation in habitat conditions due to climatic variation across the area.
Rule 8	As far as possible allocate biophysically variable areas to their 1750 PVC.	A complementary position to the previous rule is to identify areas where the greatest variation occurs in a small area as this is likely to offer increased biodiversity opportunities because of the diverse range of habitat possibilities in a restricted area. There may also be benefits from this concentration under climatic change conditions as it may offer opportunities for vegetation communities and the fauna they support to adjust by moving to counter climatic change impacts.
Rule 9	As far as possible allocate areas of land to the 1750 PVC where the corresponding 1750 EVC is under represented in the bioregion.	This rule seeks to include consideration of the broader context within which the study area sits by seeking to offset regional rarity of vegetation types that might be locally common.
Rule 10	As far as possible allocate areas that include rare and threatened species to their 1750 PVC.	Rare and threatened species are often the focus of high profile programs to prevent their total demise. Therefore attempts to increase the natural habitat requirements for rare and threatened species provides an opportunity for reducing the risk to such species and the species with which they are associated.

Rule 11	As far as possible allocate areas near remnants with higher canopy density to their 1750 PVC.	The concept of habitat hectares recognizes a number of onsite and offsite factors that contribute to the overall assessment. This guideline seeks to identify areas that have the greatest potential to increase Habitat Hectare assessment by influencing offsite factors relating to the spatial proximity of other vegetation patches. Higher canopy density is assumed to indicate higher remnant quality.
Rule 12	As far as possible allocate areas of higher remnant patch density to their 1750 PVC.	The concept of Habitat Hectares recognizes a number of onsite and offsite factors that contribute to the overall assessment. This guideline seeks to identify areas that have the greatest potential to increase Habitat Hectare assessment by influencing offsite factors relating to the spatial proximity of other vegetation patches.
Rule 13	As far as possible allocate areas near remnants of larger size to their 1750 PVC.	The concept of Habitat Hectares recognizes a number of onsite and offsite factors that contribute to the overall assessment. This guideline seeks to identify areas that have the greatest potential to increase Habitat Hectare assessment by influencing offsite factors relating to the size of proximal vegetation patches
Rule 14	As far as possible allocate areas near streams to their 1750 PVC.	Stream bank plantings are seen as providing particularly high ecological opportunity for a number of reasons. Firstly, streamlines in agricultural areas often occupy some of the more productive land and have therefore been largely cleared of native vegetation. These areas are frequently the only watering points for domestic stock and therefore any remaining native vegetation is at continual risk as these points regularly become high-density congregation points. As a consequence, stream banks become unprotected and vulnerable to erosion further impacting upon stream water quality. Secondly, the combination of water and native vegetation provides highly valued habitat conditions for most native fauna. Thirdly, stream bank plantings (assuming domestic stock is excluded) stabilise the banks and provide filter strip, reducing sediment and nutrient inflow to the stream. The filter strips also serve to reduce the inflow rate and therefore moderate the peak flows and erosive capacity of the stream improving in-stream habitat conditions for the stream's biota. Stream bank plantings may also intercept sub-surface groundwater moving laterally to the stream, should this groundwater be saline then the plantings may reduce entry of saline water to the stream further adding to improvement in water quality.
Rule 15	As far as possible allocate areas enclosed by remnant vegetation to their 1750 PVC.	Infill plantings allow existing disparate plantings to be coalesced into a larger area by a block planting filling the void between the disparate plantings. Because of the viable area requirements of some species infill plantings may transform two non-viable areas into a single viable area.
Rule 16	As far as possible allocate areas that provide short linkages between remnant vegetation to their 1750 PVC.	Corridors provide a linking conduit between isolated patches enabling species movement up and down the corridor to the terminal patches. However, corridors have also been criticised as providing conditions easily exploited by feral predators preying upon native fauna as they attempt to move along the corridor.
Rule 17	As far as possible allocate areas further from high productive value land to their 1750 PVC.	This rule seeks to identify areas that are currently (or foreseeably) used for alternative high value land uses. By recognizing this aspect the likelihood that areas will come under threat from competing land uses in the future can be minimized and therefore be areas selected for management for biodiversity should be at lower risk in the future.
Rule 18	As far as possible allocate areas currently containing non-PVC vegetation types to their current vegetation type.	This rule provides an allocation rule against which the other rules compete. Otherwise all land would be allocated to PVC s.

Note: The rules were based on catchment objectives, ecological theory and design principles adopted for the CSIRO Heartlands Project. In this table "allocating areas to their 1750 PVC" means that land that has been cleared of native vegetation is managed towards the PVC that was believed to cover it before it was cleared or modified.

Table 9.3 shows the weights and rules aggregated into groups relevant to policies and practices in the conservation of native biota: CAR criteria (comprehensiveness, adequacy, representativeness); social imperatives; and other environmental benefits. The weights reflect the relative importance given to landscape process in providing conditions where native species can persist and flourish. The inclusion of a full range of vegetation communities was thought to be of secondary importance.

9.2.6 Generation of future options

In all, eleven mapped options for future native vegetation enhancement were generated as well as the map of current vegetation pattern. Figures 9.3 to 9.5 show examples of current vegetation pattern, vegetation at a 15% areal target and vegetation at a 40% areal target. A 15% target is commonly used in catchment management documents and also for State priority setting. At a 40% target the landscape has become relatively well connected. At this point many ecosystem services show a non-linear response to increasing vegetation in the landscape (this influence of space on connectivity is discussed later in this report, see Section 9.3). Current vegetation was modelled using tree canopy and 1750 EVC as a base map with cropping rotations assumed below 160m above sea level (ASL) and native perennial pasture above this contour. This assumption was validated with satellite imagery and field visits. Exotic perennial pasture is assumed to occur along roadsides adjacent to streamlines.

The grid data model used in this analysis biases estimates of areas in two ways:

1. the area of PVC on the grid map of current vegetation is about 14%. The on ground mapped area is 8%. The reason is many existing remnants have dimensions smaller than 100m. We have represented current vegetation at 8% on the graphs of changes in ecosystem services; and

Table 9.3 Decision group and rule weightings for the biodiversity ehancement scenario

Decision Group	Decision Rule
Comprehensiveness (0.20)	Reflect previous distribution (0.2006)`
Adequacy (0.45)	Near to dense remnants (0.0175) High patch density (0.0767) Near to larger remnants (0.0920) Enclosed by remnants (0.0822) Provides linkages (0.1814)
Representativeness (0.12)	Spatially dispersed (0.0366) Biophysically variable (0.0790)
Social imperatives (0.07)	Regionally rare (0.0410) Rare species present (0.0210) Avoids areas of high value for production (0.0111)
Other environmental benefits (0.16)	Near to drainage (0.1609)

Note: The rules have been paraphrased to reduce the size of the table. Weightings shown in parentheses.

2. because some vegetation types currently cover up to 21% (30% in the grid representation) of their 1750 distributions, small re-vegetation targets produce more actual native vegetation than the target implies. Using the example of a 20% target, this is satisfied when all vegetation types are present at a minimum of 20% of their assumed 1750 distributions. To achieve this 22% of the sub-catchment needs to be re-vegetated. Those vegetation types that are most locally depleted therefore show the most rapid increase in extent at small aerial targets (< 30%).

9.2.8 Evaluation of ecosystem services

The inventory process (Binning and others 2001) identified the ecosystem services deemed most important by community representatives. These included: pollination; human fulfilment; regulation of climate; pest control; maintenance of genetic resources; maintenance and regeneration of habitat; provision of shade and shelter; filtration and erosion control; maintenance of soil health; provision of healthy waterways; regulation of river flows and ground water levels; waste absorption and breakdown. Of these, seven were considered tractable for evaluation in Sheep Pen Creek based on the existence of models or empirical relationship that responded to changes in vegetation extent and pattern. Table 9.4 lists the services and the indicators and functions used to evaluate them. In the following figures and discussion the eight percent target values are derived using the current vegetation pattern.

Figure 9.3 Modelled current vegetation

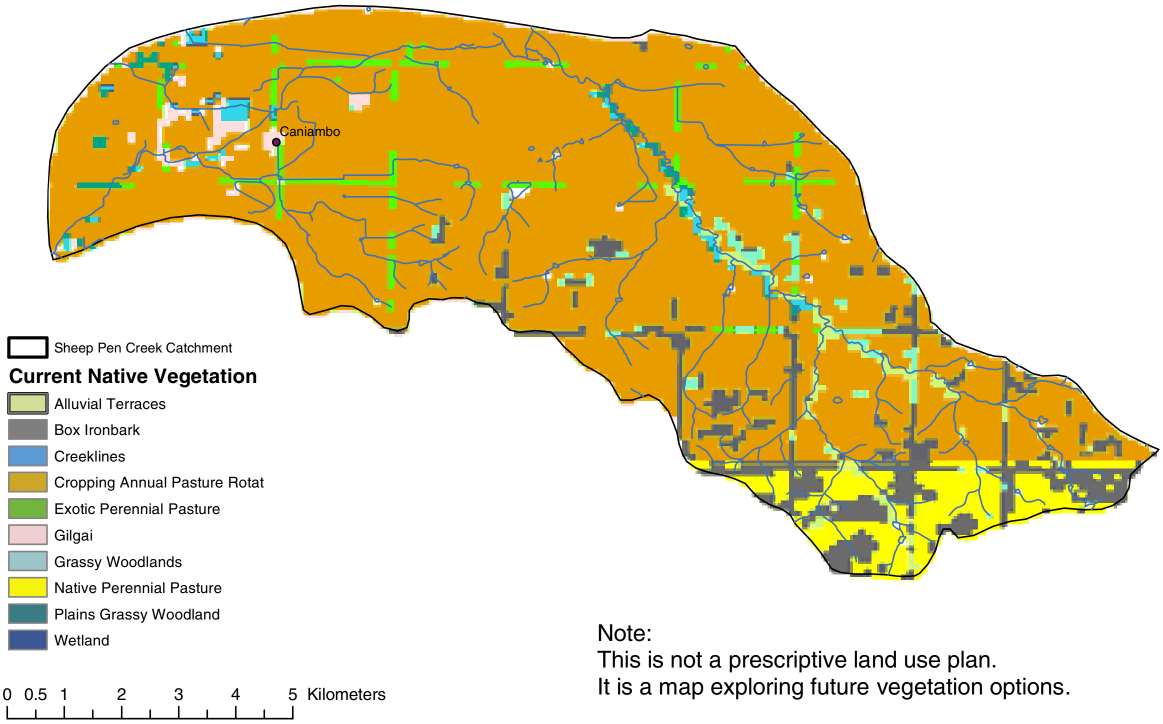


Figure 9.4 Modelled 15% target for native vegetation enhancement

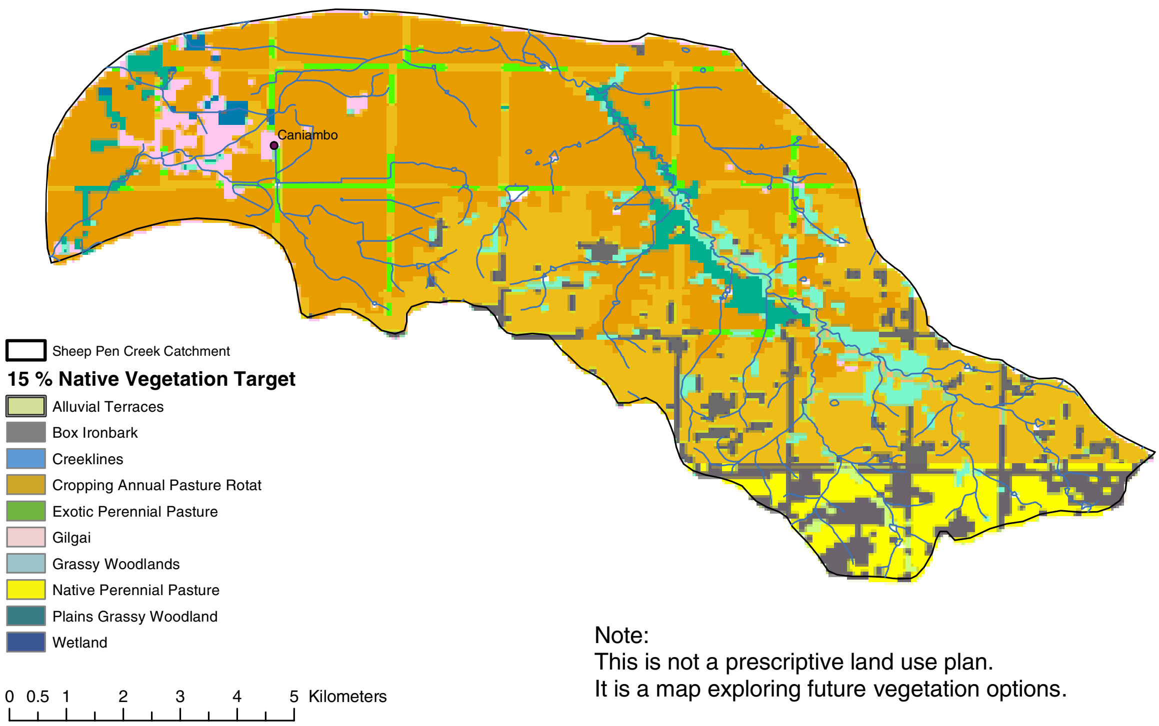


Figure 9.5 Modelled 40% target for native vegetation enhancement

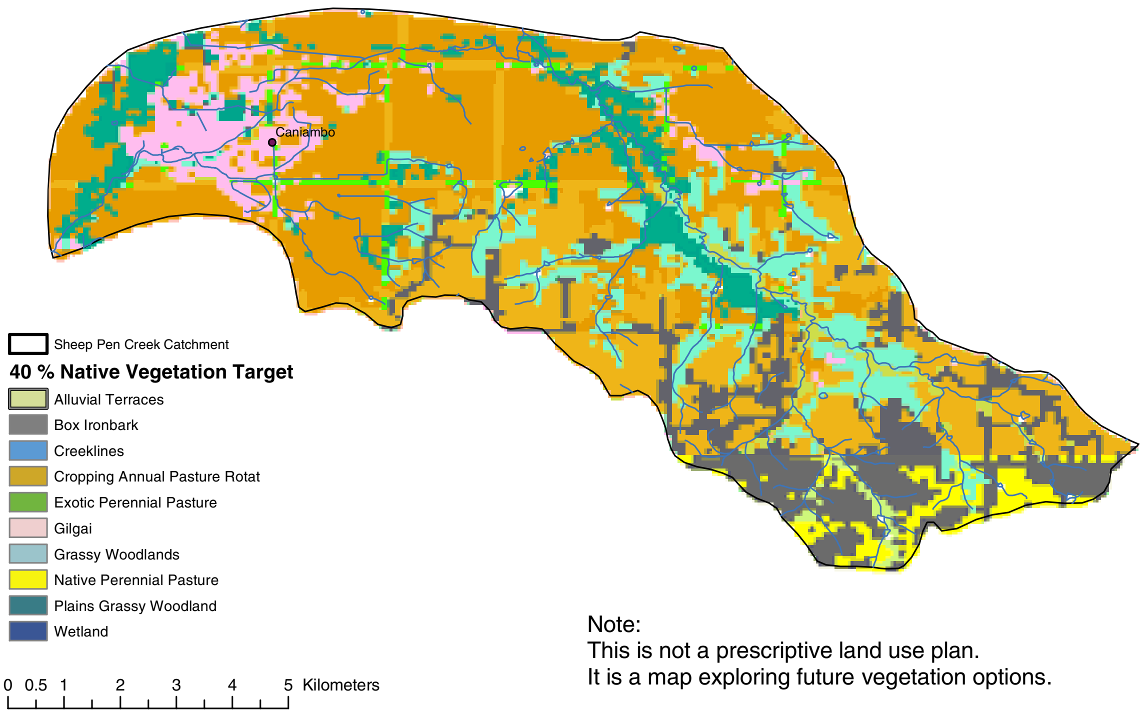


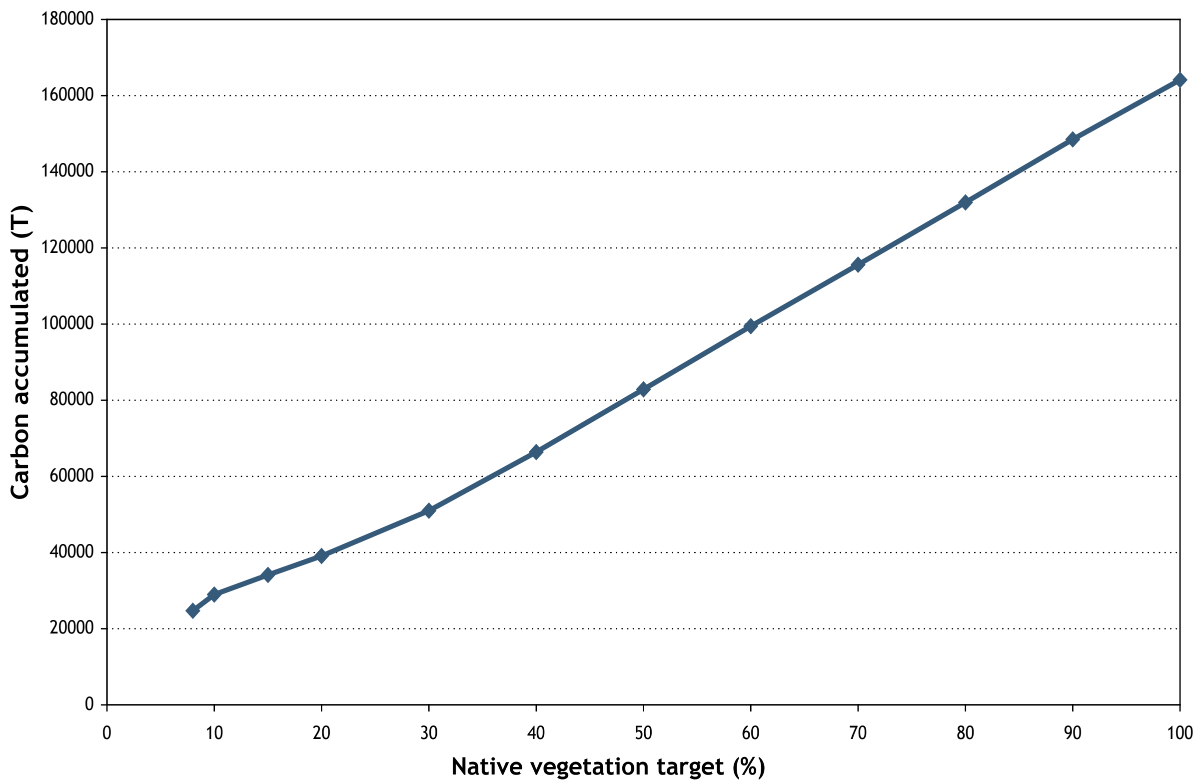
Table 9.4 Ecosystem services evaluated for the case study

Ecosystem service	Indicator	Functions
Regulation of climate	Carbon accumulated	Carbon Mass (T) = total stem dry matter + (total root dry matter * 0.5)
Maintenance and regeneration of habitat	Habitat Configuration Score	Habitat Configuration Score = NRE Habitat Hectares (patch size (maximum of 10 units) + neighbourhood score (maximum of 10 units) + distance to core area (maximum of 5 units)
Provision of shade and shelter	Area protected	Shade Benefit = area (ha) of total perimeter of woody vegetation / total area in production Shelter = sum(area (ha) of B cells + C cells * 0.5) Where: 'A' cells are the line of grid cells adjacent to the vegetation downwind from a vegetation strip more than three cells wide perpendicular to the prevailing wind. 'B' cells are cells adjacent to and downwind of any 'A' cells. 'C' cells are 2 rows downwind immediately adjacent to 'B' cells.
Maintaining healthy waterways	Bank Erosion	BE(m/year -1) = 0.00002 x p x g x Q_x x S_x (1- PR)(1-e -0.008^{F_x}) Where: 'p' is the density of water (kg/m^3); 'g' is acceleration due to gravity (m/sec); 'Q_x' is mean annual stream flow (megalitres); 'S_x' is energy slope (channel gradient, m); 'PR' proportion of the stream with riparian vegetation (m); and 'F_x' is the floodplain width (m).
Water filtration and erosion control	Erosion risk	Revised Universal Soil Loss Equation (Rosewell 1993) A = R * K * L * S * P * C Where: 'A' is the gross annual soil loss in t/ha, 'R' is the rainfall erosivity factor in Erosion Index units; 'K' is the soil erodibility factor, which is the rate of soil loss per erosion index unit measured on a standard plot under bare fallow; 'L' is the slope length factor, defined as the ratio of soil loss from a particular slope length to that from a 22.1 m slope length under otherwise identical conditions; 'S' is the slope steepness factor, which is the ratio of soil loss from a particular gradient to that from a 9% slope under otherwise identical conditions; 'P' is the soil conservation management factor. No conservation practices were assumed;and 'C' is the cover management factor, defined as the ratio of soil loss under a particular level of cover to the loss from a bare fallow.
Regulation of river flows and ground water	Water Yield to Channel Deep drainage rate	Water Yield (ML/y) = modelled yield (Spatial Framework & APSIM) Deep Drainage (ML/y) = modelled yield (Spatial Framework & APSIM)
Maintenance of soil health	Soil acidification risk	Acidification Risk(years to critical pH) = Initial pH + Buffering Capacity (kmol (+) /ha) pH-1)/ Acidification Rate Capacity (kmol (+) /ha pH-1)

Climate regulation

The service "climate regulation" was evaluated using total carbon accumulated in woody vegetation as an indicator. The sequestration of carbon in woody vegetation is seen as a key strategy to off-set carbon dioxide emissions and combat global warming (Department of Natural Resources and Environment 2002a). The function used is a standard equation for calculating the total carbon accumulated in standing woody vegetation and does not include soil carbon stocks (Howden and others 1994). The EVC Benchmarks (Department of Natural Resources and Environment undated a and b) were used to determine stem densities of dominant species for each vegetation class at maturity and average tree heights were based on figures from local forestry assessments (Department of Conservation Forests and Land 1986; Harvey pers comm.). Carbon accumulation in shrubs and other understorey was not included as the carbon contribution of these structural elements in the Sheep Pen Creek vegetation types is considered minor. The function produces a linear response when applied to the vegetation targets, with total carbon accumulated increasing as the total area of vegetation increases (Figure 9.6). Potentially 164,000 T of carbon could be sequestered if the entire catchment was covered by native vegetation compared to 34,000 T at a 15% native vegetation target and 66,000 T at a 40% target

Figure 9.6 Carbon accumulated for each native vegetation enhancement target



Maintenance and regeneration of habitat

The service "maintenance and regeneration of habitat" describes the ecosystem's capacity to provide the habitat required for native species to survive and flourish. Habitat is defined by both its internal structure and distribution across space. For vegetation communities internal structure includes the species present and their relative abundance. As discussed earlier (Section 9.2.3), it was not possible to analyse these aspects of habitat. The spatial aspects of habitat were analysed using the three neighbourhood components of the Department of Sustainability and Environment's (DSE) Habitat Hectares tool (Parkes and others 2003): patch size, distance to core area and number of patches in the surrounding area. These were implemented using raster GIS algorithms developed in the project and are referred to as Habitat Configuration Scores (Figure 9.8).

There are two important inflection points in the graph of rate of increase in Habitat Configuration Scores (a measure of marginal gain) in Figure 9.7. Between 8 and 10 percent the Habitat Configuration Scores increase because the spatial configuration switches from one solely influenced by current vegetation patterns to one influenced by both current vegetation and the decision rules. This occurs because the current vegetation patterns are controlled by historical land clearing events and the decision rules tend to create greater connectivity. Between 10 and 30 percent targets the rate of increase of the Habitat Configuration Score diminishes relative to the target gain because the native vegetation is not yet connected across the landscape. After 30 percent the landscape becomes more connected and the Habitat Configuration Score increases at a faster rate than the target gain.

Figure 9.7 Habitat configuration score and native vegetation targets

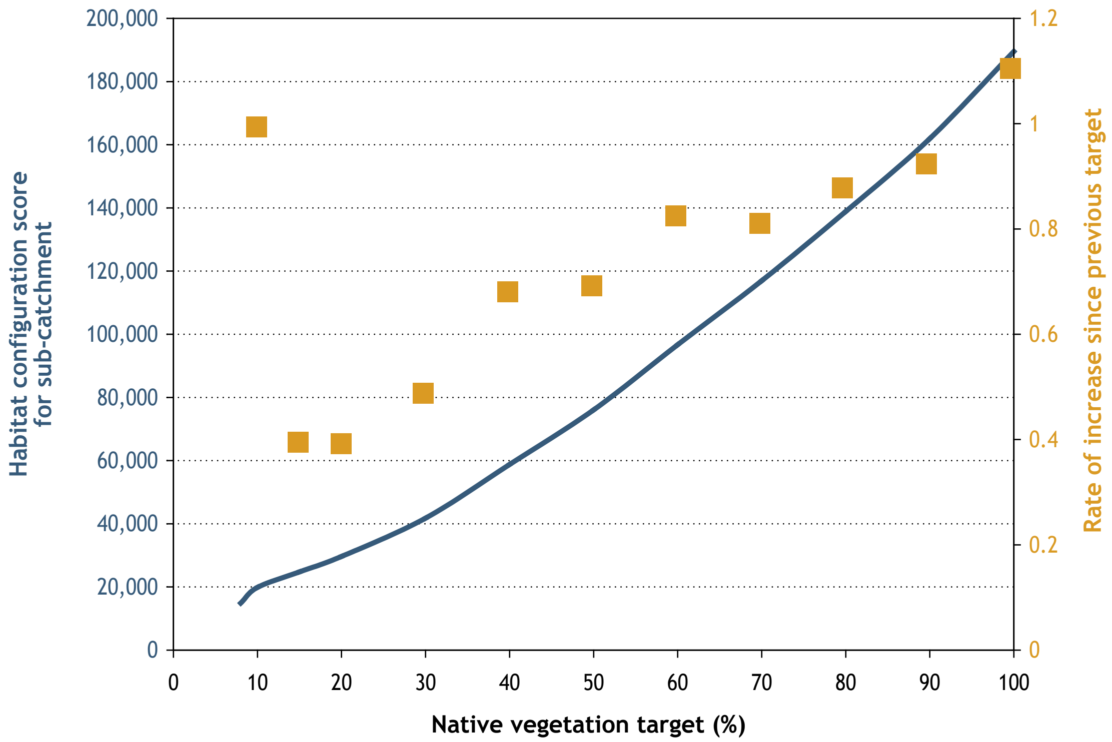
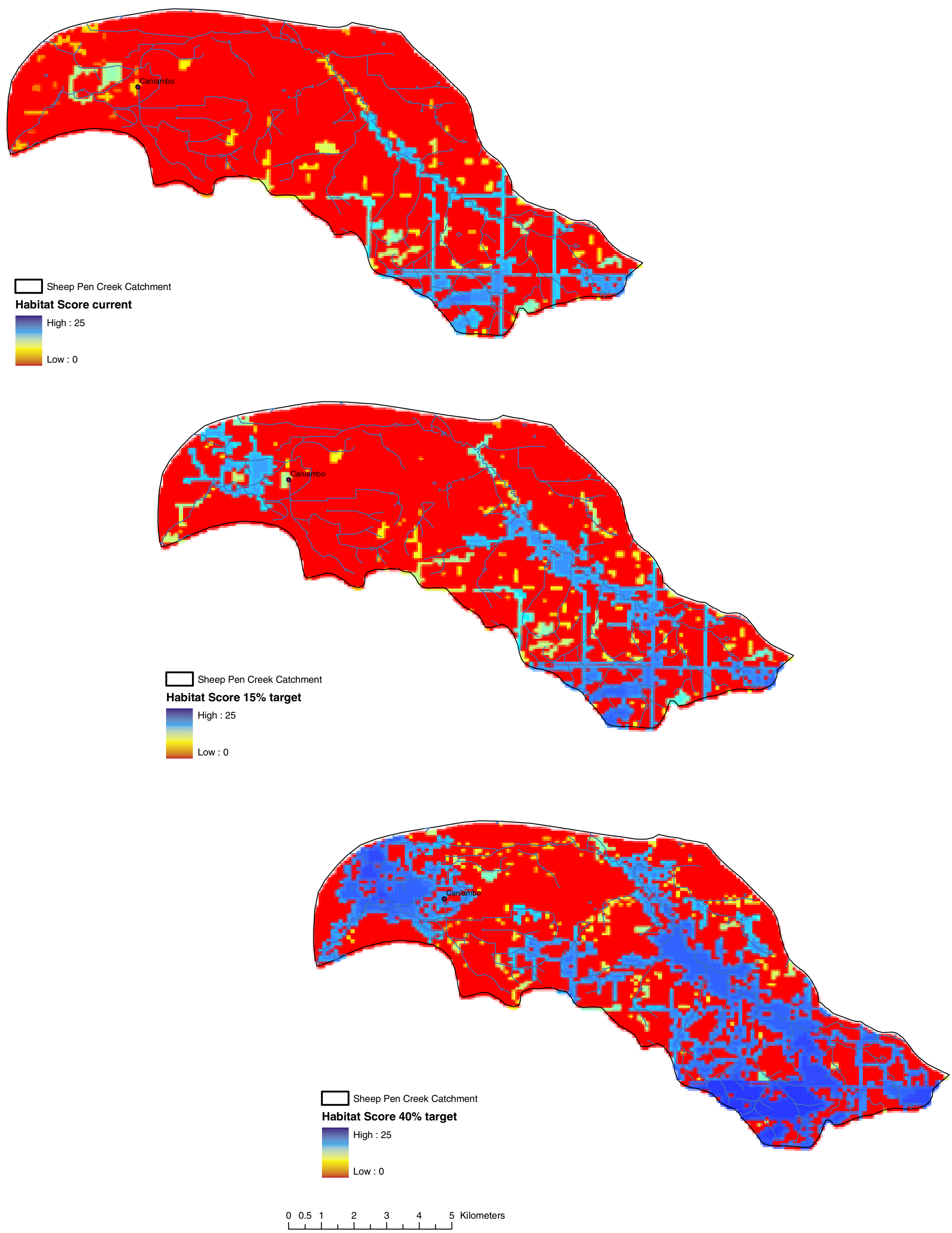


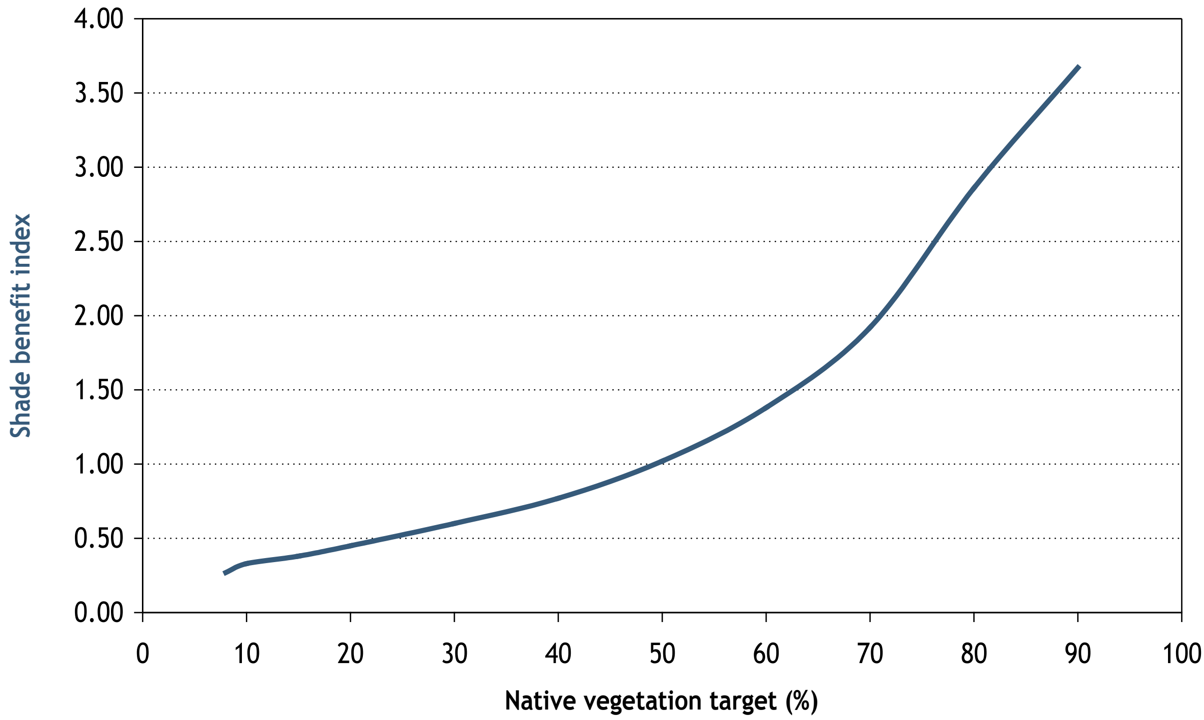
Figure 9.8 Habitat configuration scores at the current, 15 and 40 percent native vegetation enhancement targets



Provision of shade and shelter

The service "provision of shade and shelter" was considered to influence production in three ways. First, the effect of wind shelter on crop and pasture growth. Second, the effect of wind shelter on animal production through reduction in animal stress and mortality (particularly of newborn animals and shorn sheep). Third, the effect of shade on animal production (animal stress through high temperature). For shelter, wind protection zones (Haines and Burke 1993) were defined and implemented using raster GIS algorithms developed in the project. The zones are referred to as the competition zone, the quite zone, and the wake zone. The competition zone is where vegetation competes with pasture or crops for nutrients, water and light. It extends out from the leeward side of the shelterbelt less than 3 H (where H is the mature shelterbelt height, which we assumed to be 15m). In this zone wind is significantly reduced. This zone is scored 0 because the benefits gained by reduced evaporation and increased temperatures are offset by the losses associated with resource competition. The quiet zone is where resource competition is minimal and increases in plant growth and yield are expected due to increased daytime temperatures and reduced evaporation from wind. It extends out from the leeward side of the shelterbelt between about 5 to 10 H. This zone is scored 1.The wake zone extends out from the leeward side of the shelterbelt more than 10 H. This zone is scored 0.5. At about 20 H wind speed is similar to unsheltered sites. The shelter score is an accumulation of areas by benefit of each zone. The shelter benefit index (Figure 9.10) is the shelter score normalised by the area under agricultural production. The total benefit peaks at the 40% native vegetation target whereas the shelter benefit index peaks at 70%. For shade all locations adjacent to woody vegetation are considered to be shaded. Shade benefit is an index of the length shaded normalised by the area under agricultural production (Figure 9.9).

Figure 9.9 Provision of shade for each native vegetation enhancement target



Note: Shade benefit = shaded area / agricultural production area.

Figure 9.10 Provision of shelter for each native vegetation enhancement target

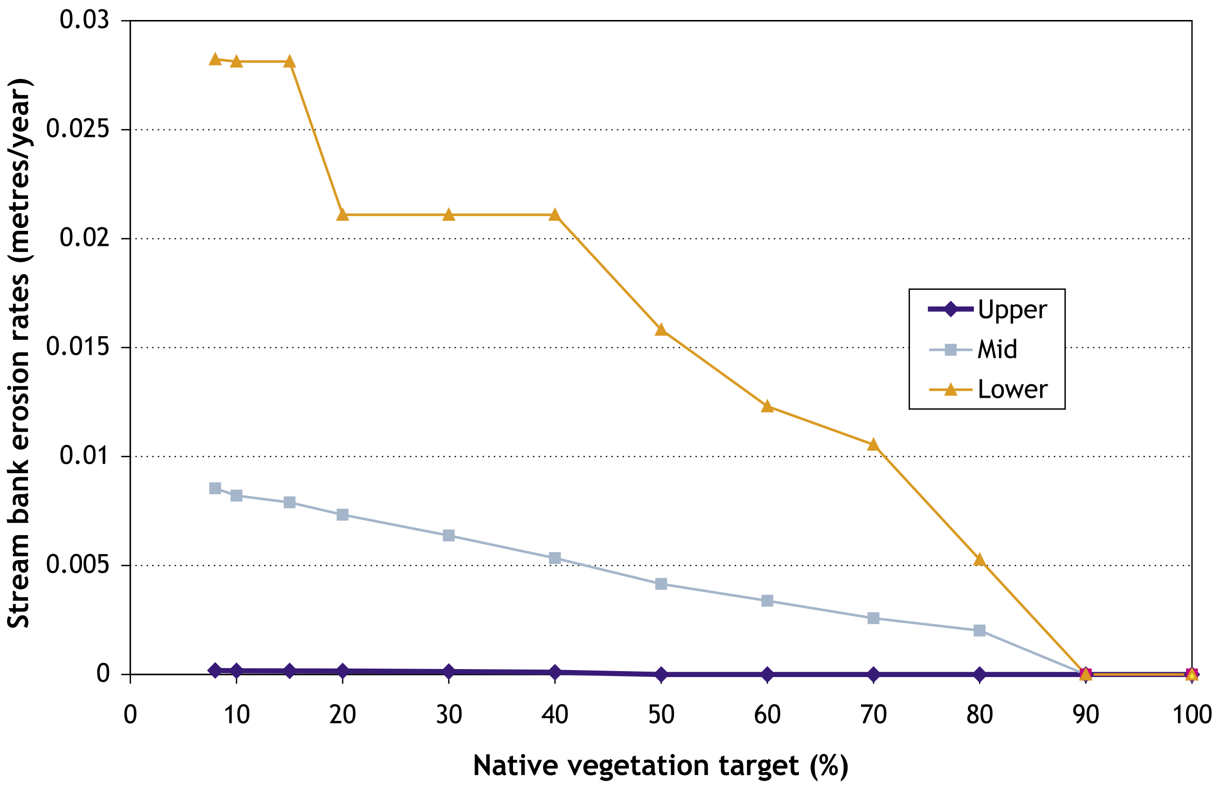
Note: Shelter benefit = shelter score / agricultural production area.

Maintaining healthy water ways

Stream bank erosion was used to evaluate the service "maintaining healthy water ways" as this indicator encapsulates both in-stream and near-stream health. The function used to calculate bank erosion is based on stream power and includes annual stream flows and the proportion of the stream bank that is vegetated, inputs which both vary according to the vegetation cover targets. Bank erosion, measured in meters per year,contributes to approximately one third of the sediment load of streams in this area of the Goulburn Broken catchment, which in turn has implications for nutrient loads, particularly sediment transported phosphorous (DeRose and others 2003) . Bank erosion rates were calculated for the upper, mid and lower sections of Sheep Pen Creek, which account for 45%, 51% and 3% of the total stream length respectively. Bank erosion rates calculated under current condition in this study are generally within the ranges of those modelled by DeRose and others (2003), except in the lower stream section where our analysis suggested higher rates than those reported by DeRose and others (2003) for the same section of stream. This is most likely due to the lower proportion of riparian vegetation obtained from the more detailed vegetation mapping data used in our study, than the more coarse scale mapping used by DeRose and others (2003).

Figure 9.11 illustrates the changes in bank erosion rates with increasing vegetation cover. Two key assumptions affect the estimates. First, reduction in bank erosion occurs only when vegetation is added to grid cells that are intersected by the stream network. Second, average annual stream flow has not been reduced to account for increasing catchment vegetation cover. Consequently erosion rates are probably over estimated for vegetation targets above 'current' cover of 8%.

Figure 9.11 Stream bank erosion for each native vegetation enhancement target



Note: Upper, mid and lower refer to sections of the sub-catchment.

While the results for the Lower section of Sheep Pen Creek indicate the greatest reduction in bank erosion rates, this section of the stream accounts for only 3% of the total length of the creek. Additionally this section of Sheep Pen Creek occurs in an area with proportionally more highly depleted PVCs and consequently significant areas of vegetation are added to this location first in the initial allocations of revegetation.

Water filtration and erosion control

Erosion risk was used to evaluate delivery of the ecosystem service "water filtration and erosion control". Erosion risk was modelled using the Revised Universal Soil Loss Equation (RUSLE) (Rosewell 1993). The RUSLE model uses rainfall erosivity, soil erodibility, slope length and steepness, and soil and crop management practices to produce estimates of the quantity of soil moved by sheet and rill erosion per hectare per year. We applied the model to the grid of one hectare cells, and assumed a slope length of 30m in each. The result is an erosion hazard map, not an estimate of the quantity of soil actually removed in a year. Cover estimates for PVCs were taken from the Ecological Vegetation Class benchmarks for native vegetation (DNRE undated a and b). Cover was estimated for production vegetation types. The RUSLE does not predict catchment sediment yield as the equation does not account for re-deposition or sediment from bank and gully erosion.

As the cover in each vegetation type is assumed to be fixed, and because erosion rates are significantly lower under native vegetation than under the production vegetation types, the total annual gross soil loss in the catchment decreases in a linear fashion as agricultural land is progressively reallocated to native vegetation to achieve the desired targets (Figures 9.12 and 9.13).

Figure 9.12 Gross soil loss for each native vegetation enhancement target

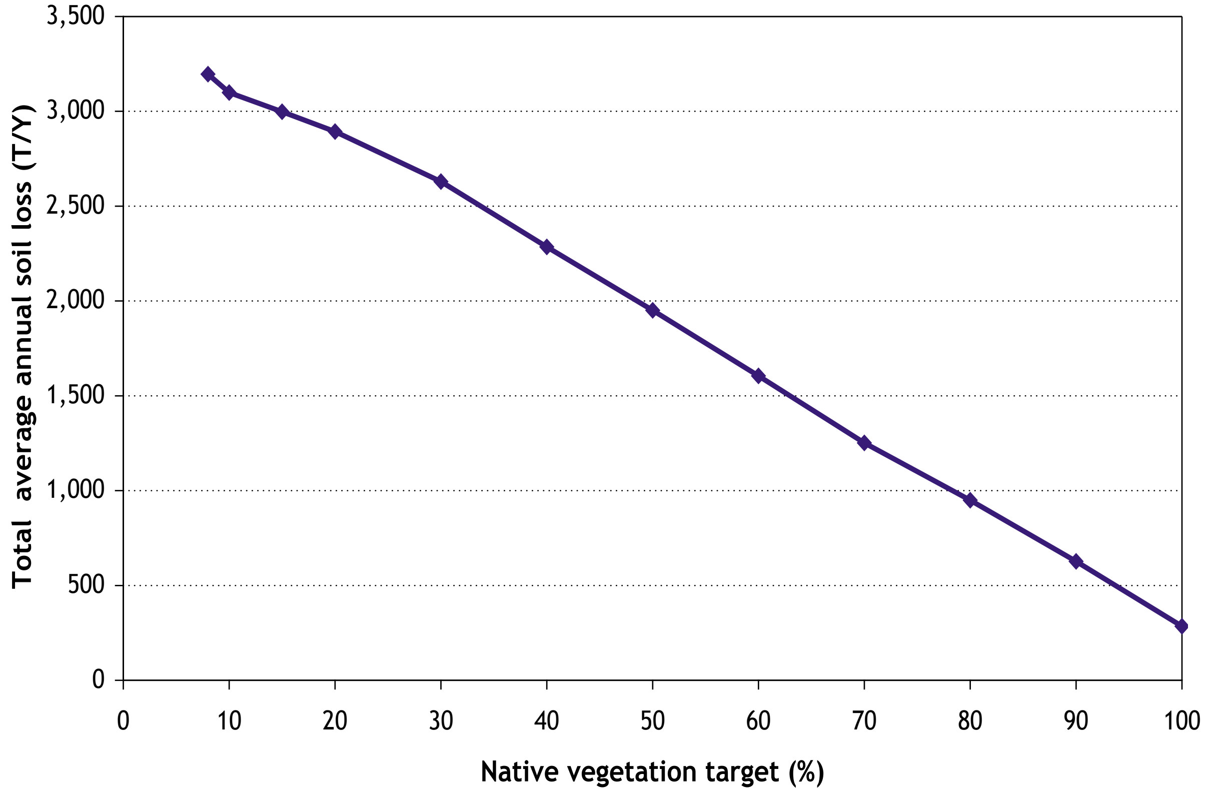
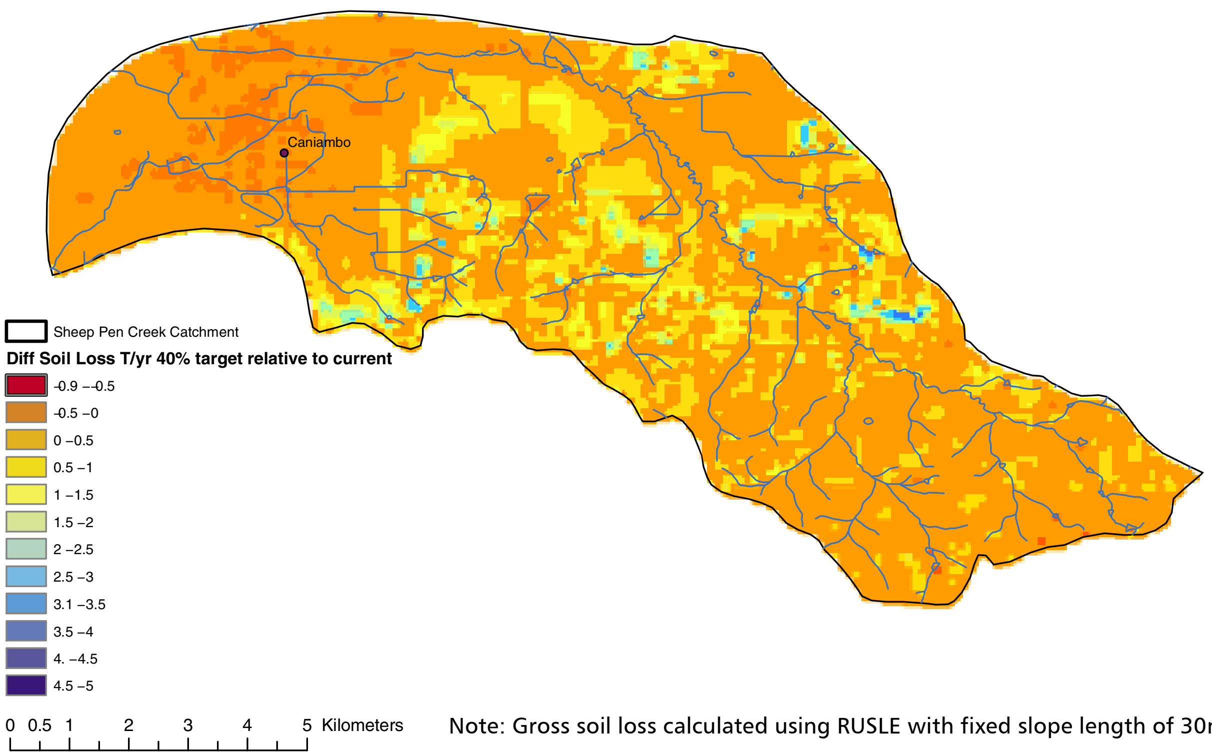


Figure 9.13 Change in gross soil loss when native vegetation is increased from current to 40% target



Note: Gross soil loss calculated using RUSLE with fixed slope length of 30m.

Regulation of river flows and ground water

The service "regulation of river flows and ground water" was evaluated in three steps:

1. Delineation of the catchment into 30 hydrological units representing 12 sub-catchments and 3 landscape positions; uphills, slopes and valleys. This was accomplished using a multi-resolution valley bottom flatness (MRVBF) index derived from an algorithm developed by Gallant and Dowling (2003);
2. Characterisation of hydrological units by major soil types, hydrological characteristics and vegetation classes as determined for the 12 biodiversity scenario options; and
3. Implementation of a hydrological framework developed by Gallant and others at CSIRO Land & Water.

This procedure enabled the farming model APSIM (Keating and others 2003) to be used across the landscape, incorporating interactive effects of lateral flow and runoff. It accomplished this for each hydrological unit of the landscape by collecting the water outputs of the APSIM model runs, scaling them appropriately, migrating the water across the landscape, and running further instances of the APSIM model in downstream hydrological units. Water yield to the channel from the headwater through progressively lower hydrological units to the end of the catchment was estimated for the different vegetation targets (Figure 9.14). The method estimates the amount of water draining to groundwater and so is indicative of the potential impact of changing land use on the water table (Figures. 9.15, 9.16).

Annual average water yield to channel and water lost to deep drainage both decrease as woody vegetation cover increases. Interestingly, whereas water loss to deep drainage under the current vegetation is about 1.5 times the water yield to channel, as native vegetation approaches 100% of total area relative water loss to deep drainage rises to 3 times that yielded in the channel. Decreases in water yield in this model reflect increasing interception and evaporation from the canopy of the woody vegetation, and the reduction in runoff due to increased permanent litter cover. Decreases in deep drainage reflect the reduction in rainfall reaching the ground through canopy interception and increases in transpiration due to access to water deeper in the soil profile by deep rooted woody perennials. While decreases in water lost to deep drainage is directly proportional to the cover of woody perennials, the largest marginal decrease in channel yield occurs under the 40% vegetation target relative to the 30% target, and in the 50% relative to the 40% target. This reflects the greater allocation of native vegetation to units close to channels under these targets. However, while these differences are statistically significant, in absolute terms they are relatively small.

Figure 9.14 Water yield to channel for each native vegetation enhancement target

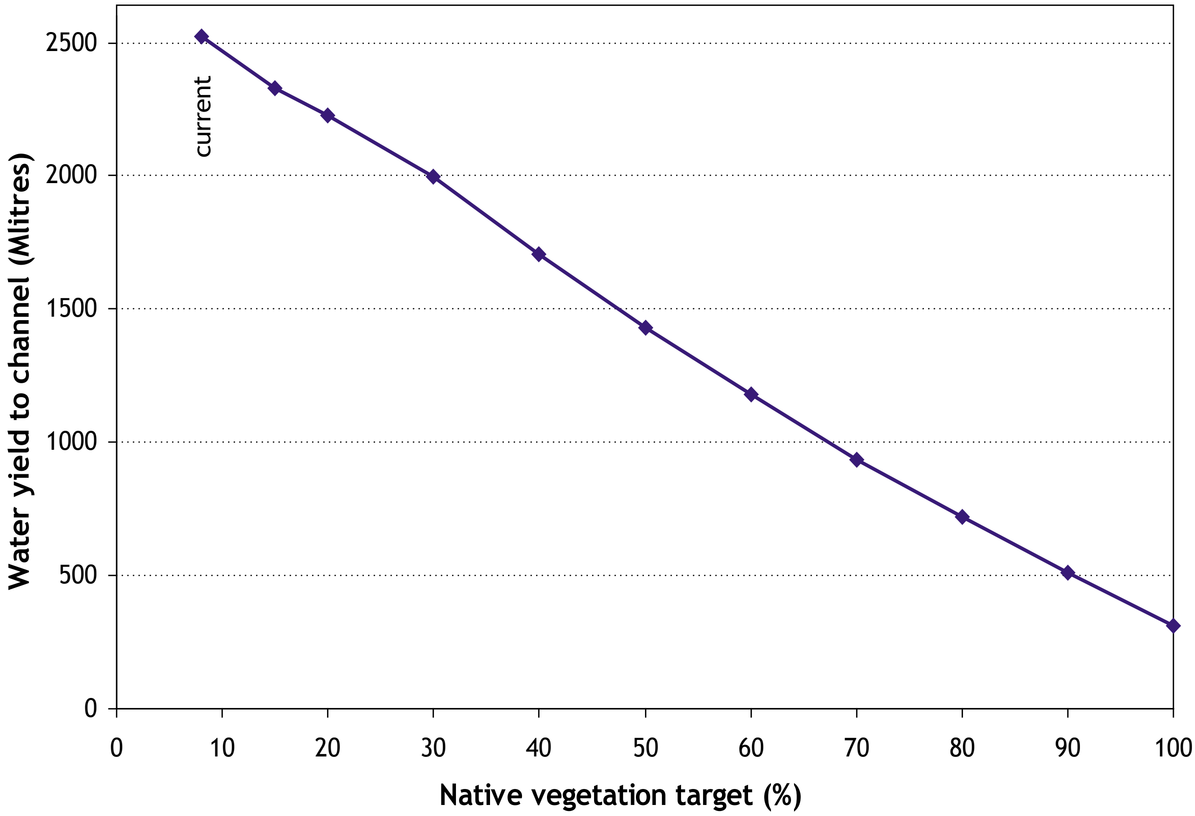


Figure 9.15 Water yield to deep drainage for each native vegetation enhancement target

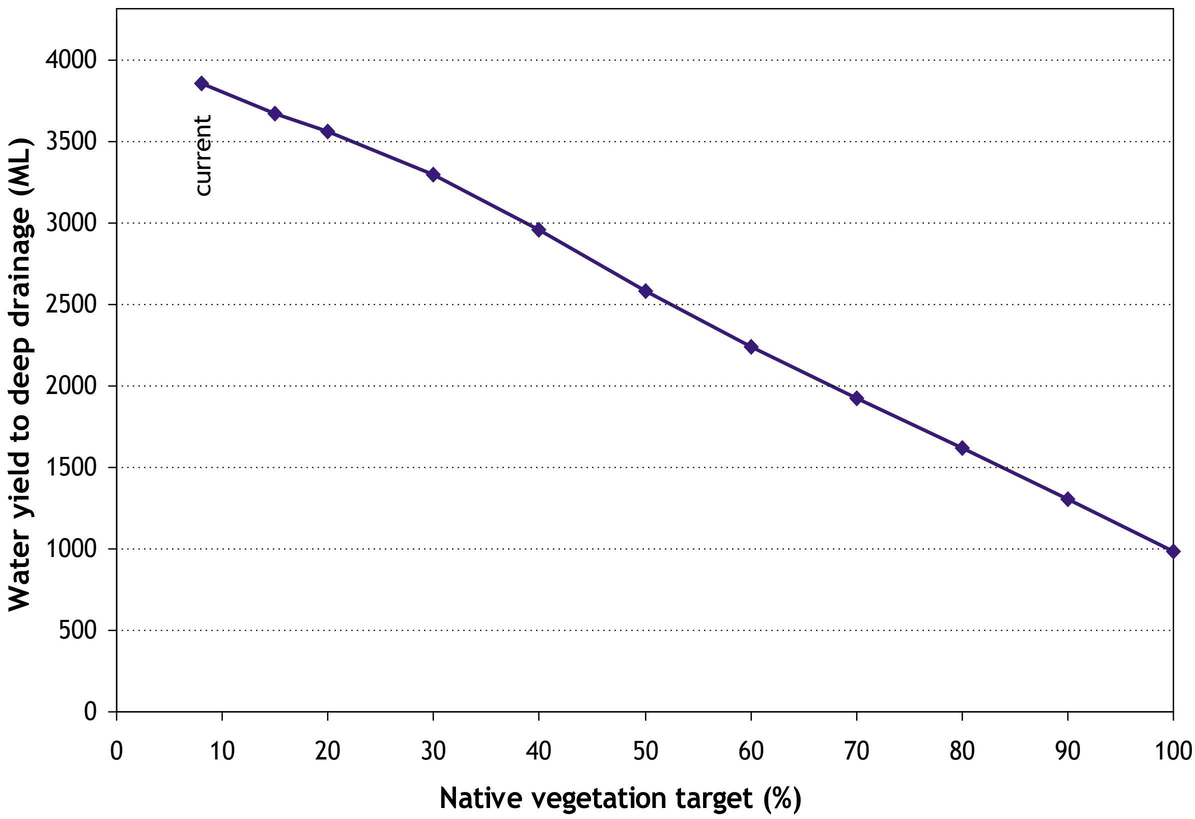


Figure 9.16 Water yield to deep drainage for the current, 15 and 40 percent native vegetation enhancement target

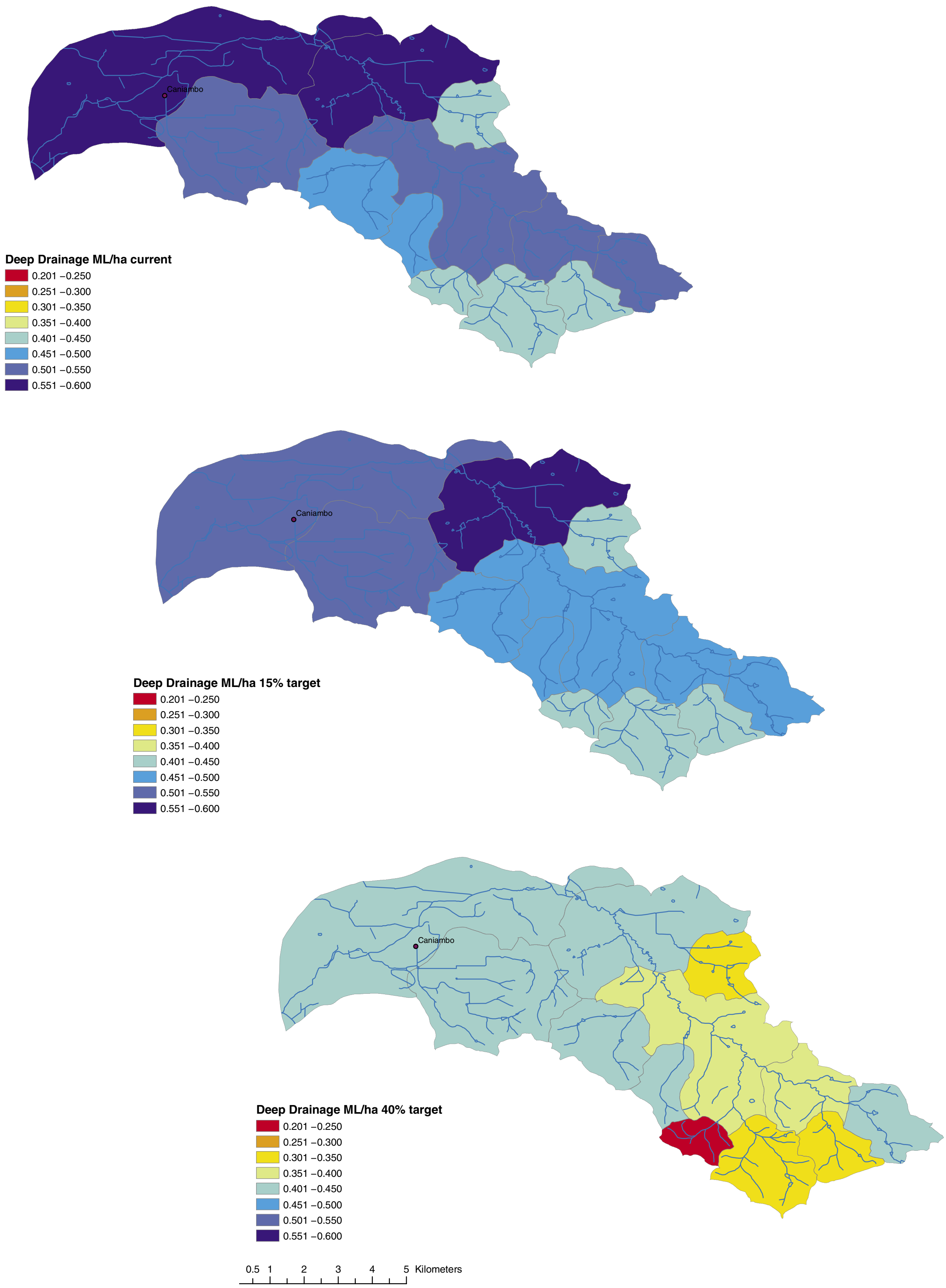
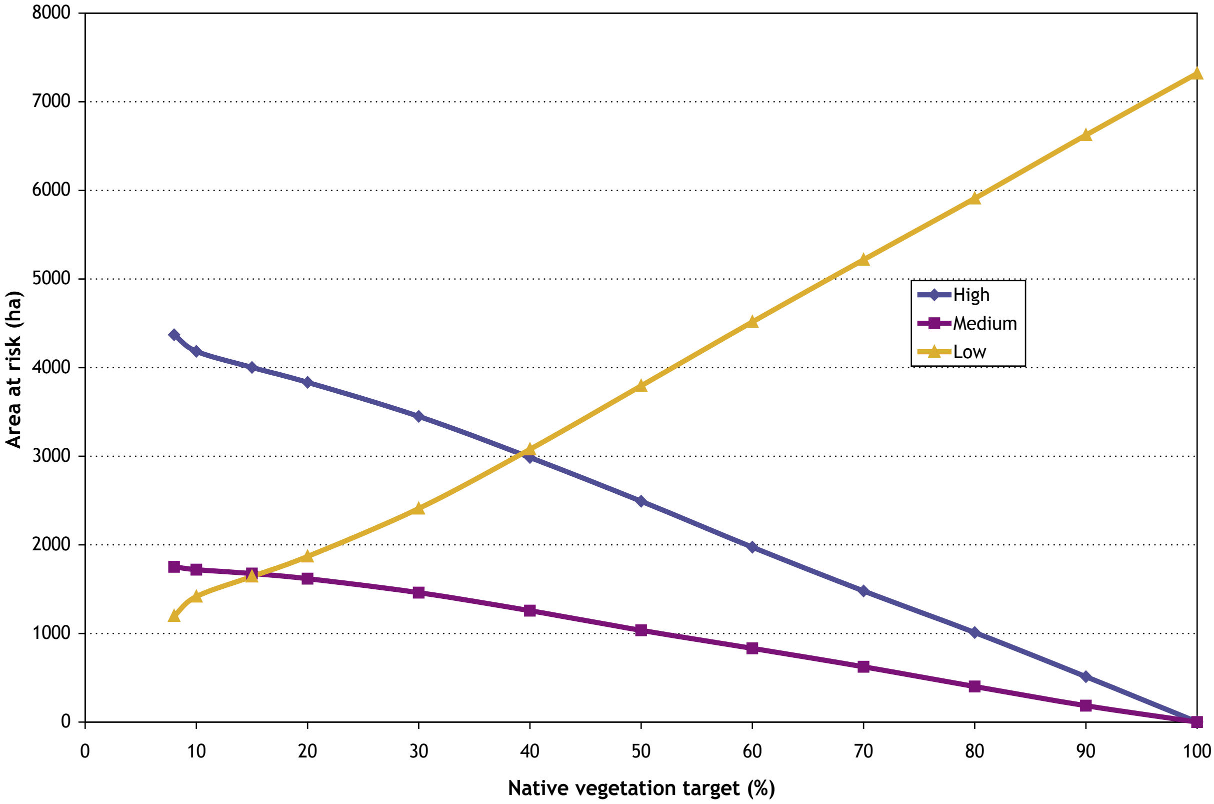


Figure 9.17 Soil acidification risk for each native vegetation enhancement target

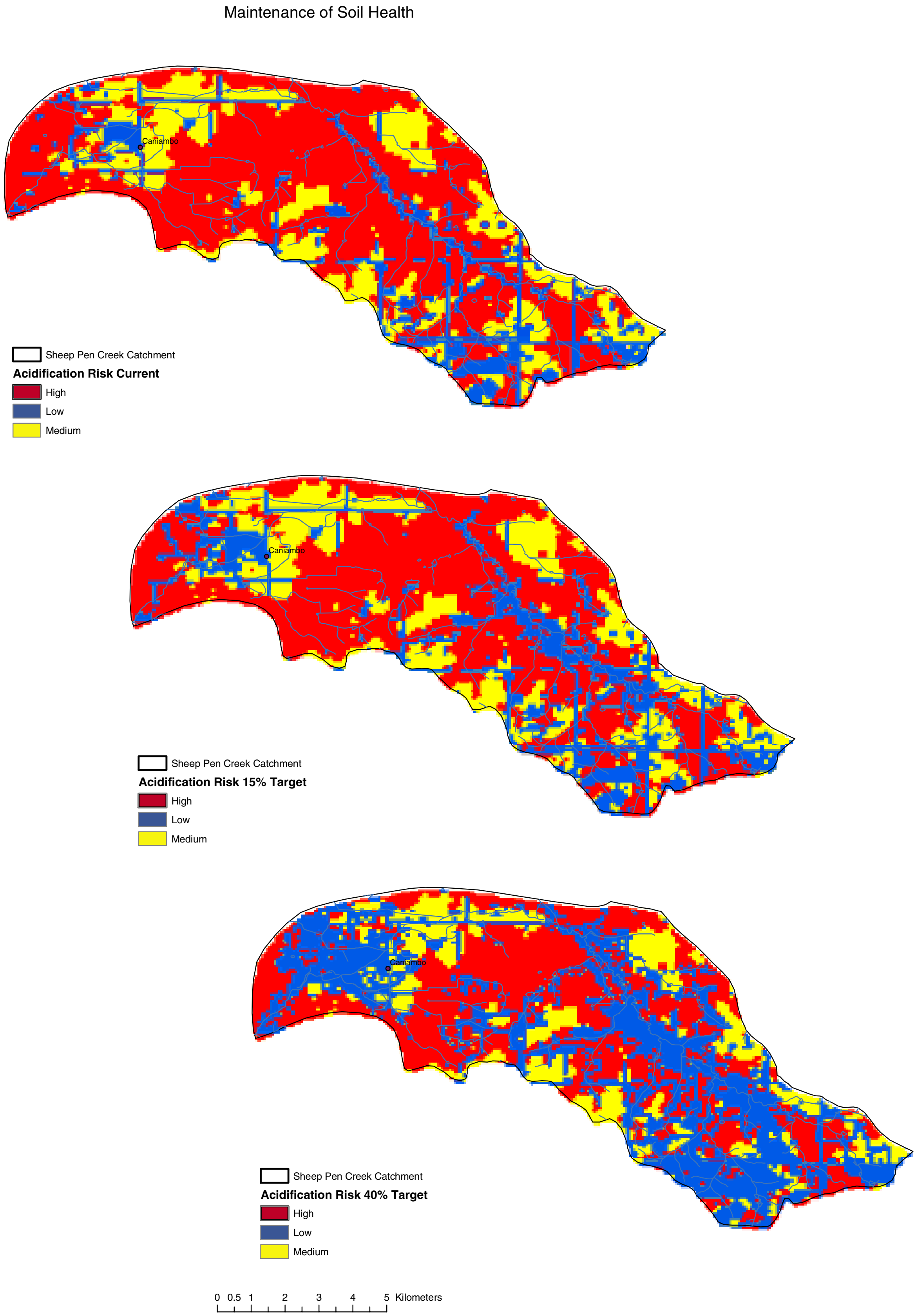


Note: High risk = <15 years until pH5; Medium risk = 15–30 years until pH5; low risk = >30 years until pH5.

Maintenance of soil health

Soil acidification risk was used as an indicator of the ecosystem service "maintenance of soil health". Soil acidification risk is a function of existing soil pH (all pH values referred to in this case study are expressed in 0.01M $CaCl_2$), the capacity of the soil to resist acidification (buffering capacity) and the acidification rates of various vegetation and crop types (Helyar and others 1990; Hill 1999; Department of Natural Resources and Environment 2002b) and is calculated for the topsoil layer only. Existing pH was assigned to grid cells from soil survey data for the region (Department of Natural Resources and Environment 2001), while buffering capacity was calculated using attributes from a variety of data sets. Acidification rates under various vegetation and crop types are based on a review of available data by Slattery and others (1999). The critical threshold for pH was set at 5, a point beyond which acidity is likely to impact on production and limit crop selection (Hill 1999). The data are expressed as years until the critical threshold (pH 5) is reached (Figure 9.18), risk categories being: High Risk (<15 years), Medium Risk (15–30 years) and Low Risk (30+ years). The inflection points (Figure 9.17) in the High and Low categories from the current vegetation cover (8%) to the 15% target reflect the initial reallocation of vegetation types from production vegetation types to native vegetation. In the initial stages this occurs in the proportionately most depleted vegetation types, which are likely to occur in cropping/pasture areas, the vegetation types with the highest acidification rates. Reallocation of these areas to native vegetation results in a reduction of acidification risk for these areas from High to Low. Following these inflections, the area at High Risk declines steadily as areas currently under agricultural production are progressively reallocated to native vegetation.

Figure 9.18 Soil acidification risk for the current, 15 and 40 percent native vegetation enhancement target



9.3 Interactions and trade-offs among ecosystem services

Non-linear responses of ecosystem services to changes in vegetation may contain thresholds important for policy, planning or management, especially in relation to the ratio of environmental gains versus investment. Several potential sources of non-linearity exist:

- differential interactions in the response of biophysical process relative to change in vegetation;
- conflicting decision rules producing vegetation options that switch at critical points; and
- spatial dependency of services on neighbouring vegetation.

However, only the last effect was evident in the evaluation of services in Sheep Pen Creek. For the most part the formula used to link service indicators with vegetation were derived from empirical studies and involved simple linear combinations of landscape attributes (e.g. carbon sequestration, nutrient yields, erosion risk and soil acidification). Those indicators such as water yields that were derived from dynamic modelling that also typically depended on linear relationships. Heterogeneity in data inputs, another source of non-linearity, in these models was relatively low. For the biodiversity enhancement, scenario decision rules were all complementary and thus not a source of non-linearity. This would not necessarily be the case if the rules for all scenarios were combined for an analysis of the tradeoffs between production and environmental benefit.

The primary source of non-linearity in ecosystem service responses was spatial interaction. This generally occurred at three points as native vegetation targets increased from 8–10%, from 30–40% and from 80–90%. Services that displayed spatial dependence with native vegetation include 'maintenance and regeneration of habitat'; 'provision of shade and shelter'; 'water filtration and erosion control'; maintaining healthy waterways; and to a lesser degree 'regulation of ground water and river flows'. Most of these have both onsite and offsite benefits. For these services planning for placement of vegetation across the landscape will be critical and if well considered could provide multiple benefits with minimum investment. In contrast the services 'regulation of climate' and maintenance of soil health' were not influenced by spatial arrangement of native vegetation. For these services, or at least the indicators used to measure them, the service response is linked simply to the amount of native vegetation present in the landscape.

The service 'maintenance and regeneration of habitat' has non-linear responses at three levels of native vegetation cover. The first is between the current cover and the 10 percent target. The spatial configuration of the current remnant vegetation reflects land use choices historically made by individual landholders. The configuration of the 10 percent option builds on these remnants by applying the decision rules for the biodiversity enhancement scenario, thus changing the influences on spatial pattern from production to conservation-oriented controls. The marked increase in the Habitat Configuration Score per unit of cover at this threshold reflects a high return to investment in conservation over this narrow range of cover.

The second inflection point for this indicator occurs around 30–40 percent vegetation target (Figure 9.7 — Habitat Configuration Score). Initial investigation of this suggests that around 30 percent is when, on average, large parts of the landscape becomes well connected.

The third threshold occurs for some services (e.g. shade and shelter) at relatively high vegetation targets. For such services the benefit of the vegetation is expressed as proximity to the vegetation. As the landscape is filled with native woody vegetation the opportunity for find such sites reduces.

Policies for allocation of resources to native vegetation enhancement need to accommodate these non-linear responses of Habitat

Configuration Score. Large gains per unit of cover were achieved where the initial pattern of remnants led to the creation of clusters of native vegetation. In contrast, if the same vegetation target was achieved using plantings dispersed more widely across the landscape it is likely the Habitat Configuration Scores would be lower because of the reduced likelihood of having high connectivity and patch size. Given a fixed amount of expenditure available for vegetation enhancement, it might be better to concentrate funds in several small areas rather than disperse it across the landscape. Note this is one perspective only and should be considered in light of other ecosystem services and as well as other ecological and social values.

9.4 Conclusions and lessons learned

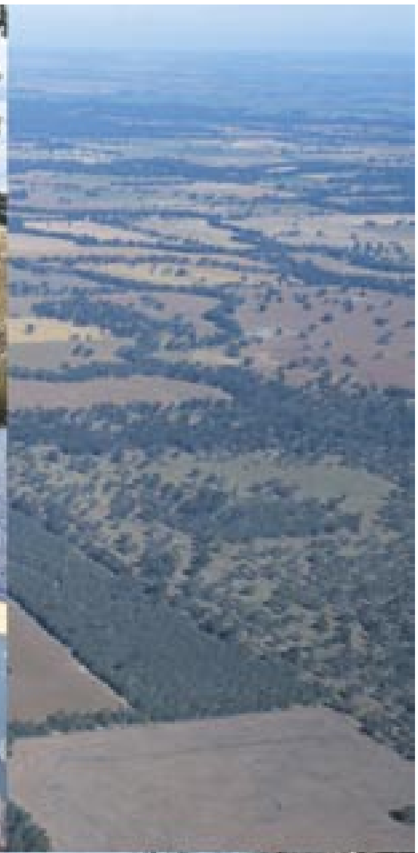
The full list of project outputs, observations and considerations is given at the beginning of this chapter.

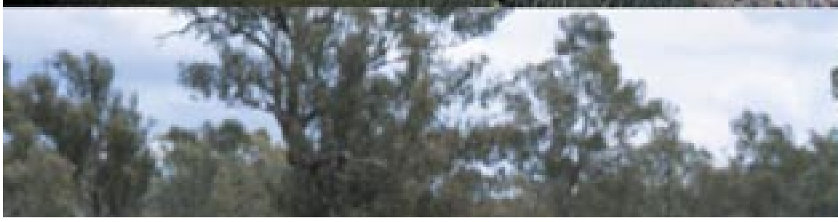
The scenario approach proved to be an effective way of quantifying responses of ecosystem services to various vegetation targets, and exploring thresholds and trade-offs.

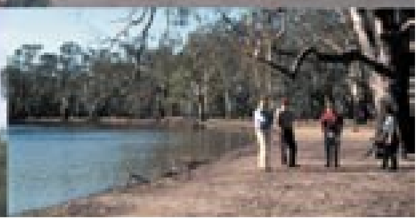
The analytical approach we have taken is to apply wherever possible simple and empirical rules for the evaluation of services. This is not to say that applying more complex dynamic process models is not warranted. However, such models (e.g. of water yields) are only useful when they provide understanding in addition to that provided by the simple empirical relationships. The trade off for these approaches is that the greater the complexity in the evaluation process the more opaque the process becomes to the catchment community.

Also for simplicity, we have only included ecosystem services and indicators that were readily tractable. This does not infer they are key services in the sub-catchment, either from an ecological point of view or from the point of view of the community. In Section 12 we present a framework for prioritising investment in research and management of ecosystem services. This framework suggests that ‘maintenance of soil health’ and ‘maintenance of genetic resources’ are as least as high a priority as ‘maintenance and regeneration of habitat’. For maintenance of soil health we used acidification risk as the service indicator. Whilst topical for the community it is by no means the only attribute of soil health we might wish to evaluate. However, little is known about the empirical responses of soil organisms and resulting soil condition to changes in native vegetation. We did not evaluate maintenance of genetic resources. While considerable theory exists about meta-populations and flow of genetic material, with the exception of population viability analysis, this tends to be explanatory rather than predictive. For valuation purposes indicators need to be predictive.

The vegetation types associated with agricultural production contribute to the provision of most of the ecosystem services we have analysed, but they generally do so to a much smaller amount than native vegetation. The indicator for the service “provision and regeneration of habitat” was Habitat Configuration Score. It is based on the Department of Natural Resources and Environment system that gives zero habitat value to agricultural vegetation types, which is clearly not correct. It is clear from the comparison of the vegetation options for different targets that ecosystem service provision increases across all services as the native vegetation increases. We have quantified this increase in terms of service indicators, but the task of relating these indicators to human benefit remains to be achieved.







10 Ecosystem services supporting tourism and recreation

10 Ecosystem services supporting tourism and recreation

Wendy Proctor

The aim of the case study is to test a deliberative decision making process that will aid in resource use planning involving multiple decision makers and complex issues such as ecosystem services.

10.0 Case study highlights

Project outputs include:

- an impact matrix showing a list of decision criteria, relevant indicators for the criteria and the values of these indicators under different options for future management of recreation and tourism in the upper catchment;
- a list of priorities of the main decision criteria for recreation and tourism management is provided by the key natural resource managers;
- for the purposes of the recreation and tourism analysis the most important ecosystem services identified as being crucial in the decision-making process could be aggregated to Water Quality, Water Quantity, Biodiversity and Aesthetics; and
- a deliberative decision-making process was developed and successfully tested to aid in the process of resource use planning and management, in particular, when complex issues (such as ecosystem services) are involved.

Key observations from workshops and analyses are:

- ecosystem services are high priority considerations in recreation and tourism management;
- more research is needed on:
  - public access issues and ways to limit access effectively;
  - the effects of education on tourism and environmental damage and whether or not education of tourists would be effective in maintaining ecosystem services;
  - effective methods for recovery of management costs and whether or not user pays and access charge schemes would be effective;
  - the role of market and other instruments in limiting damage
  - the effects of introducing a code of practice for tour operators and whether this will benefit ecosystem services; and
  - the need to reduce the number of public managers of natural resources with jurisdiction in any one area.

Key considerations are:

- in group decision-making processes involving complex issues such as ecosystem services, it is crucial to clearly identify and define the decision criteria involved;
- a deliberative process, where learning is enhanced by expert presentations and decision-makers are asked to declare and defend their priorities can aid in achieving consensus; and
- the ecosystem services framework is robust — it provides sufficient detail to allow focus but is capable of lumping or aggregation of services and allows for communication of key issues even where high uncertainty exists.

10.1 Introduction

The upper catchment is renowned for the opportunity for the nearby population of Melbourne (3.4 million people) to enjoy the magnificent scenery and tourism activities that are offered there including skiing, four wheel driving, bushwalking, camping, horseriding or just sightseeing. The influx of tourists each year however have caused serious environmental problems for the area which need to be addressed quickly.

This study addresses three of the overall project objectives within the context of recreation and tourism management in the upper catchment. In particular, this research

- estimates the benefits and other impacts of ecosystem, economic and social decision criteria to help resource managers take account of their inter-relationships under various resource use scenarios;
- attempts to raise awareness of the values of maintaining ecosystem function with natural resource managers; and
- provides a method that recommends policies and practices that maintain these values.

These objectives are met by addressing the complex issues of tourism management in the upper catchment using a deliberative process aided by Multi-criteria Evaluation. In identifying and prioritising the ecosystem services and other decision criteria, recommendations for improved management of recreation and tourism in the upper catchment are made.

10.2 Method

The method used in this analysis is called Deliberative Multi-criteria Evaluation and is based on a combination of the Citizens' Jury technique and Multi-criteria Evaluation. The Citizens' Jury is based on the model that is used in western-style criminal proceedings and often involves a public decision-making process (such as the allocation of health funds or the identification of protected natural resource areas) (Crosby 1999). The typical jury ranges from around 10 to 20 participants. The jury can be selected either randomly or by use of a stratified random sample to make it representative of the population. The jury is usually remunerated for their efforts and is given a specific charge which is well worded, clear and direct. Ideally the process uses a facilitator and the jury is given sufficient time to deliberate, ask questions and call 'witnesses' (or 'experts'). The final outcome is usually a consensus position reached by the jury.

Multi-criteria Evaluation (MCE) is a means of simplifying complex decision-making tasks which may involve many stakeholders, a diversity of possible outcomes and many and sometimes intangible criteria by which to assess the outcomes (Massam 1988). In many public decision problems, such as those involved with environmental policy, the objectives of the decision may conflict and the criteria used to assess the effectiveness of different policy options may vary widely in importance. MCE is an effective technique in which to identify trade-offs in the decision-making process with the ultimate goal of achieving compromise. It is also an important means by which structure and transparency can be imposed upon the decision-making process

A Multi-criteria Evaluation seeks to make explicit the logical thought process that is implicitly carried out by an individual when coming to a decision. In complex decision-making tasks, which sometimes involve many objectives and many decision-makers, this structured process may be lost in the complexity of the issues. In general, a MCE seeks to identify the alternatives or options that are to be investigated in coming to a decision, a set of criteria by which to rank these alternatives, the preferences or weights the stakeholders assign to the various criteria and an aggregation procedure by which the criteria-specific rank orders are aggregated into a single "compromise" rank order. The last step should involve an extensive sensitivity and robustness analysis (Roy 1998) to explore how different preferences affect the outcome of the aggregation and how robust the compromise rank order is with respect to deviations in the preferences. The ultimate outcome is a preferred option or set of options that is based upon a rigorous definition of priorities and preferences decided upon by the decision-maker.

Multi-criteria Evaluation has the advantage of being able to provide a framework to complex decision-making problems that allows the problem to be broken down into workable units and to be structured in such a way that enables the complexities of the problem to be unravelled. This is done essentially through the process of identifying options, criteria and preferences. Applying MCE in a heuristic way enables the MCE to aid in the learning process of complex issues. In theory and in practice however, MCE does not adequately address the facilitation issue of interaction between analyst and decision-makers to elicit preferences and to revise preferences as part of the iterative process particularly with multiple decision-makers. With multiple decision-makers, MCE does not provide clear guidelines on how to analyse or aggregate multiple weights.

Citizens' Juries, on the other hand, do allow for an effective approach of interaction between multiple decision-makers and for conducting an iterative process chiefly through the deliberative aspects of the jury approach. In effect, the Citizens' Jury approach aggregates multiple preference weights through deliberation to achieve consensus. In general however, Citizens' Juries have not addressed the problem of structuring the decision-making task. Lenaghan (1999, p. 53) found that juries that had a structured and well-focused agenda performed and were able to engage much better than those that had to deal with large-scale unfocused problems.

A logical progression to overcome the problems and to enhance the advantages of both methods is to combine the two approaches.

10.3 Preparing the stakeholder jury

10.3.1 Outline of the preparatory steps

The jury chosen in this study comprised a group of natural resource managers (stakeholders) rather than randomly chosen members of the public (citizens) and has therefore been termed a Stakeholder Jury to distinguish it from the Citizens' Jury (the same procedures for the jury are applicable, however). This choice was made because of the history of the larger Ecosystem Services Project which this case study belongs to. The stakeholders had already been chosen to review issues involving recreation and tourism in the area and were therefore well placed to take part in this initial experiment on the Deliberative Multi-criteria Evaluation. Some of these stakeholders had also been involved in developing a strategy for recreation and tourism management that at the time of conducting the jury, was about to be implemented in the region.

A series of management options were devised by the group of natural resource managers in the area and a set of decision criteria developed by which these options could be assessed (see below). The options and criteria were devised at a meeting prior to the day that the stakeholder jury met.

Also prior to the jury meeting, a questionnaire was sent out to identify preliminary rankings on the set of decision criteria and to agree on a set of objectives.

The agreed objectives of the exercise were to:

- protect and enhance the environment and natural attributes of the catchment that attract recreational users; and
- balance recreational development and use of the catchment (particularly in riparian zones) with the social, environmental and economic values of the community.

The questionnaire revealed that the ranks of some of the criteria varied widely across the different stakeholders. For those criteria where there were wide disparities, expert witnesses were asked to provide information and to answer questions on the day of the jury.

An Impact Matrix showing the value of each of the criteria under each of the different options was completed by experts from various organisations. During the stakeholder jury, the Multi-criteria Evaluation software, ProDecX, was used interactively with the jurors to show the effects of changing their inputs on the criteria weightings[1]. ProDecX uses the criteria weightings provided by the jurors as well as estimates of the performance of each option with respect to the different criteria (provided in an Impact Matrix) to provide an overall ranking of the options (mean of the 'Net Flux') as well as a measure of uncertainty (standard deviation of the Net Flux) associated with these rankings.

10.3.2 Options

The workshop on recreation and tourism options was held some months prior to the jury. The procedure for the workshop was to develop a set of future land-use and management options related to recreation and tourism in the upper catchment and to identify some decision criteria for assessing these options. The following options were developed to cover as exhaustive a range of possibilities as possible.

Business as usual (Current)

This option represents the current scenario for the recreation and tourism industry in the region. Carrying on with the usual practice raises a number of concerns. These concerns include the effects of growing numbers of tourists from population increases, improved vehicles and better roads making access easier, as well as increased international demand for recreation in the area.

Maximise ecosystem services outcomes (Max ES)

This option essentially means a policy of no access to any of the recreation and tourism sites that are under threat from environmental damage (including access to national parks and state forests in the region). The benefits to ecosystem services would be immense but these would come at enormous cost to the local community from no domestic tourists and also costs to the state from a lack of international tourists. There would also be costs to all individuals in terms of the loss of aesthetic experience.

Maximise social outcomes (Max S)

This option emphasises employment for local people and therefore targets issues such as job creation and job training in the recreation and tourism industries. This includes jobs and training in such activities as ecotourism, four wheel drive tours, camping excursions, environment education tours and expansion of the local hospitality and accommodation markets. There is little concern for the impact on ecosystem services which are not noticeable to tourists (e.g. water quality) but the impacts of activities on visible ecosystem services (such as the aesthetic appeal of a site) would have to be taken into account as without these visible services there would be no tourism industry.

Maximise economic outcomes (Max Ec)

This option represents the policy of access to all areas and therefore achieves maximum short-term profits to the recreation and tourism industry. These measures would be undertaken regardless of environmental effects, e.g. there would be no concern for remedial work or conservation related infrastructure (boardwalks etc.).

[1] The software was operated by Dr. Martin Drechsler, a Visiting Scientist to CSIRO Sustainable Ecosystems, from the Centre for Environmental Research, Leipzig, Germany.

Sustainable tourism/environment/society mix (Mix)

This option essentially incorporates the items found in the Goulburn Broken Catchment Management Authority Upper Goulburn Recreational Waterway Strategy (http://www.gbcma.vic.gov.au/ugic.html). The plan represents a more balanced approach to the concerns related to environmental, economic and social issues.

10.3.3 Criteria of assessment

The options workshop also helped to identify the relevant assessment criteria. The criteria were grouped under three broad headings to reflect the desire for integrated and sustainable development in the catchment.

Ecosystem services

The emphasis of the project was in studying the ecosystem services influencing the decision-making process and so all of the potential environmental criteria involved were ecosystem services. The ecosystem services criteria are described as follows:

Maintaining water quality: Maintaining the natural purity of the water is measured by the quantity of phosphorus (P) present in the water in milligrams per litre.

Maintaining water quantity: Preserving the natural flow of the water is important for downstream users and is measured using a discharge indicator in thousands of megalitres.

Preserving biodiversity/native biota: Biodiversity (biological diversity) is perhaps most commonly defined as ``the full variety of life on Earth.'' A qualitative indicator, where 10 signifies high biodiversity and 1, low, is used.

Soil maintenance through sediment filtration/retention: This refers to the maintenance of soil and water quality through the filtering of sediments and enhancement of soil stability. This is closely linked to vegetation cover. A qualitative indicator, where 10 signifies high sediment filtration and 1, low, is used.

Erosion control: This can include the prevention of loss of soil by wind, runoff or other processes and the storage of silt in lakes and wetlands. A qualitative indicator is used to measure erosion control as defined above.

Nutrient management/waste assimilation: This includes storage, internal cycling and processing and acquisition of nutrients (e.g. nitrogen fixation). A qualitative indicator is used.

Shading: The provision of shade and shelter is closely related to vegetation and therefore biodiversity. A qualitative indicator is used to measure shading.

Stream health including instream and riparian zones: This is dependent on the level of aquatic life, the vegetation quality, stream physical form, stream flow and water quality. Here the Index of Stream Condition is used to measure stream health (see http://www.vicwaterdata.net/isc/intro.html).

Aesthetics/scenic views: This refers to the level of satisfaction derived from the visual appearance of the landscape. Aesthetic appeal is a personal quality. Often, any intervention that takes a landscape away from its natural state may be regarded as diminishing the aesthetic appeal of that area or landscape. For example, such interventions may include roads, signs, boardwalks, weeds and vehicles. However, some of these items may also be necessary to stop the landscape from deteriorating. Also some people may regard diversity in the landscape as important and so a mix of native and agricultural land uses may be aesthetically appealing. Again a qualitative indicator is used to measure aesthetic appeal.

Social and cultural

The social and cultural criteria that were considered as being important in the decision-making process on an option for recreation and tourism in the catchment were as follows:

Public access: This includes the number of people that are allowed to visit a site as well as the means by which they can visit. Here an indicator of 10 for high public access and 1 for low public access is used.

Jobs: The level of full time and part time employment that a particular scenario may involve. This is measured by the total number of people employed.

Maintenance of cultural and heritage values: The provision of measures that will maintain the integrity of sites of cultural and heritage significance. A qualitative binary indicator is used to measure this with a 0 indicating that the cultural and heritage values are not maintained and 1 indicating that they are.

Education: The provision of educational campaigns can assist in the maintenance of sites and is measured qualitatively using a 0 for not present and 1 for presence of educational campaign.

Economic

The economic criteria used in the decision-making process were limited to those that could be readily measured using existing data and included:

Costs: The monetary costs (both direct and indirect, to individuals and governments in the region) involved in the particular scenario. This can involve costs of establishing facilities at sites, weed control, fencing, lost incomes, etc. These costs are measured in dollars.

Benefits: The monetary benefits (both direct and indirect) involved in the particular scenario. This may be the benefits from increased incomes of tourist operators, accommodation providers etc. These are also measured in dollars.

10.3.4 Assessment of the options and impact matrix

An Impact Matrix showing the values of each of the different criteria under each of the different options was completed using expert input from various organisations (Table 10.1). These experts were from state natural resource and forestry management organisations, regional water management organisations, CSIRO ecologists, private consultants who had carried out research in the region as well as reports that were relevant to the information required. The matrix included both qualitative and quantitative indicators as well as ranges for some indicators that were uncertain.

10.4 The stakeholder jury: procedure and results

The jury was asked to consider the information presented to them (e.g. in the Impact Matrix and by the expert witnesses) in a facilitated and deliberative process[2]. Their charge was to come to a unanimous decision with respect to a set of weightings of the assessment criteria. The decision process, including the effect of a set of weightings on the final ranking of the recreation and tourism options, was aided by interactive use of the ProDecX software. The day was split into two sessions — the morning session with expert presentations and discussions and the afternoon session, with iterations of criteria weighting, software interaction and deliberation.

[2] The 'judge' was Dr. Gail Kelly, a Community Psychologist from CSIRO Sustainable Ecosystems with many years experience in the research and facilitation of processes involving public participation and environmental issues.

Table 10.1 Impact matrix

		Ecosystem Service Scenarios				
Criteria	Indicators	Curr.	Max ES	Max S	Max Ec	Mix
Ecosystem Services						
Water Quality	mg/L P	0.02	0.005	0.05	0.1	0.01
Water Quantity	Discharge 000 ML	150	250	100	125	150
Biodiversity/ Native Biota	10 = High 1 = Low	6	10	3	5	10
Sediment Filtration	10 = High 1 = Low	3	8	6	8	8
Erosion control	10 = High 1 = Low	7	10	7	4	7
Nutrient Management/ waste assimilation	10 = High 1 = Low	3	8	7	3	8
Shading	10 = High 1 = Low	5	10	6	2	8
Stream Health including instream and riparian zones	ISC Very poor: 0-19 Poor: 20-25 Moderate: 26-34 Good: 35-41 Very Good: 42-50	35-41	42-50	35-41	26-34	35-41
Aesthetics/ scenic views	10 = High 1 = Low	5	8	6	2	7
Social/Cultural						
Public Access	10 = High 1 = Low	5	1	7	10	5
Jobs	No. '000	15	18	20	25	18
Cultural & Heritage*	0 = not maint. 1 =maintained	0	1	1	0	1
Education*	0 = not present 1 = present	0	0	1	0	1
Economic						
Costs	$mill	2.5-3.5	0	25-3.5	0	18.3
Benefits	$mill	5.5-6.5	0	6.4-49	4.3-40.1	9-57.3

* These were added after the initial ranking process at the request of one of the jurors.

10.4.1 The Morning

The day started with descriptions of the process, the charge and the software to be used. An overview of jurors' priorities was provided showing the considerable differences in the ranking of these priorities for certain criteria (Figure 10.1). Also the results of the ProDecX run were shown indicating a top ranking to the Maximise Social Outcomes (Max S) option[3] (Figure 10.2).

The next best options were Maximise Economic Outcomes (Max Ec), Sustainable Mix (Mix), Maximise Ecosystem Services (Max ES), and lastly, Business as Usual (Current).

An important observation is that in the three best options, Max S, Max Ec and Mix, the uncertainty associated with each standard deviation (SD) was very large. This indicates that dissent on the criteria weights was so high that a conclusive ranking was not possible, i.e., no consensus on the relative ranking of these three options was achieved. Only the two worst options, Max ES and Current, with such small rankings, indicated that they were clearly outperformed by the three best options. An objective of the jury was then to improve consensus on the weights and come to a more conclusive ranking of the options.

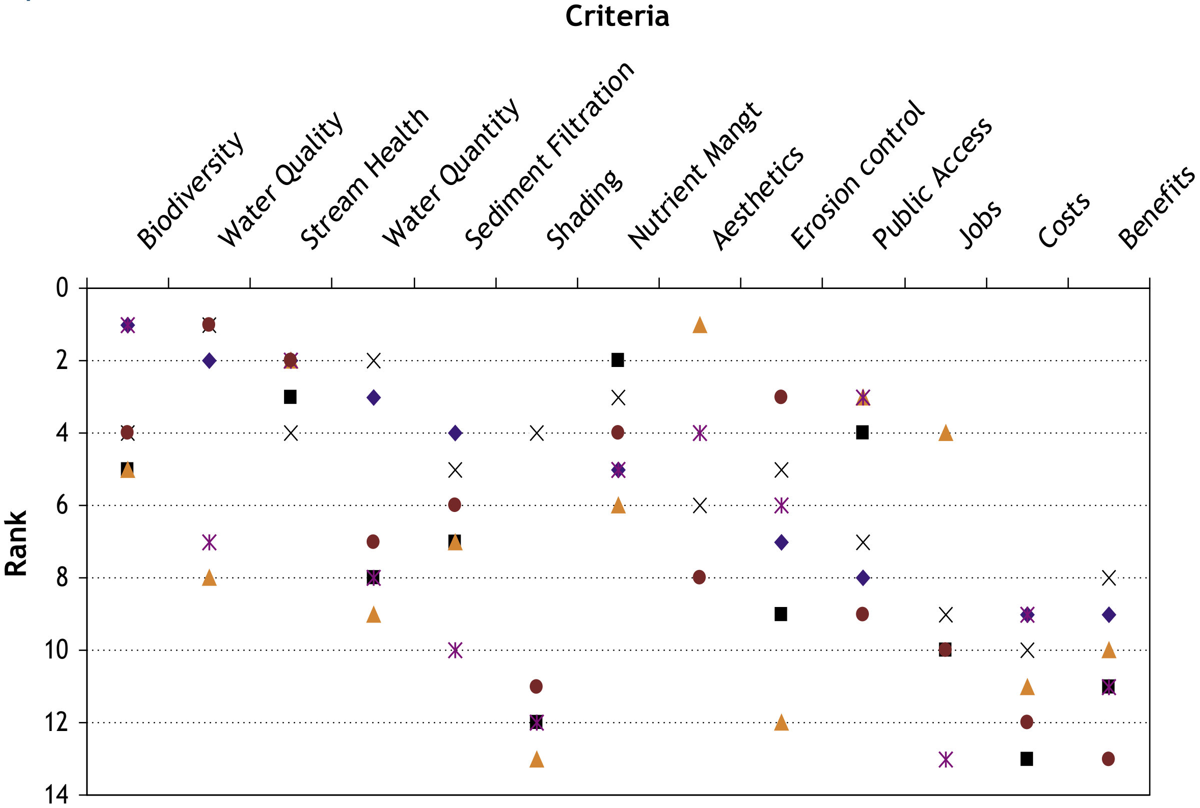
First, the jurors were asked to decide whether the three broad categories of criteria (the Ecosystem Services, Economic and Social and Cultural groups) should be weighted equally to allow for the larger number of Ecosystem Services criteria compared to the other criteria groups. After some discussion, they all agreed that such a broad weighting would reflect the desire for sustainable development in the region. Also at the request of one of the jurors, two additional criteria were added under the Social and Cultural category: the maintenance of cultural and heritage values and the provision of education.

The first witness to be called was from the local water authority and gave an overview of water quality and quantity issues relevant to the consideration of different recreation and tourism options. The issues covered included the status of storage dams, cumulative effects, effects of different types of recreation and tourism on water quality and quantity and monitoring. A great deal of discussion followed and questions from the jurors centred around the adequacy of monitoring, lessons learned from overseas experiences and whether or not education of tourists would be effective in maintaining water quality.

The next expert witness was the environmental manager from a local ski resort who spoke on public access and aesthetics. His talk highlighted issues such as sense of place, cultural identity, the importance of life fulfilling ecosystem services, the cultural icons of mountains and the injection of money into the local economy as a result of these aspects. The discussion afterwards centred around the positive effects of restricting public access such as environmental preservation, and also the issue of open access leading to an increased knowledge by the public about environmental issues. Discussion also highlighted certain user groups causing considerable environmental damage e.g. four wheel drive vehicles, motorbikes, horses and campers and whether these groups should have their access restricted. One idea that was proposed was to encourage tour groups to educate people on the effects of tourism on the environment. One way of doing this would be to introduce a code of practice for tour operators to agree to.

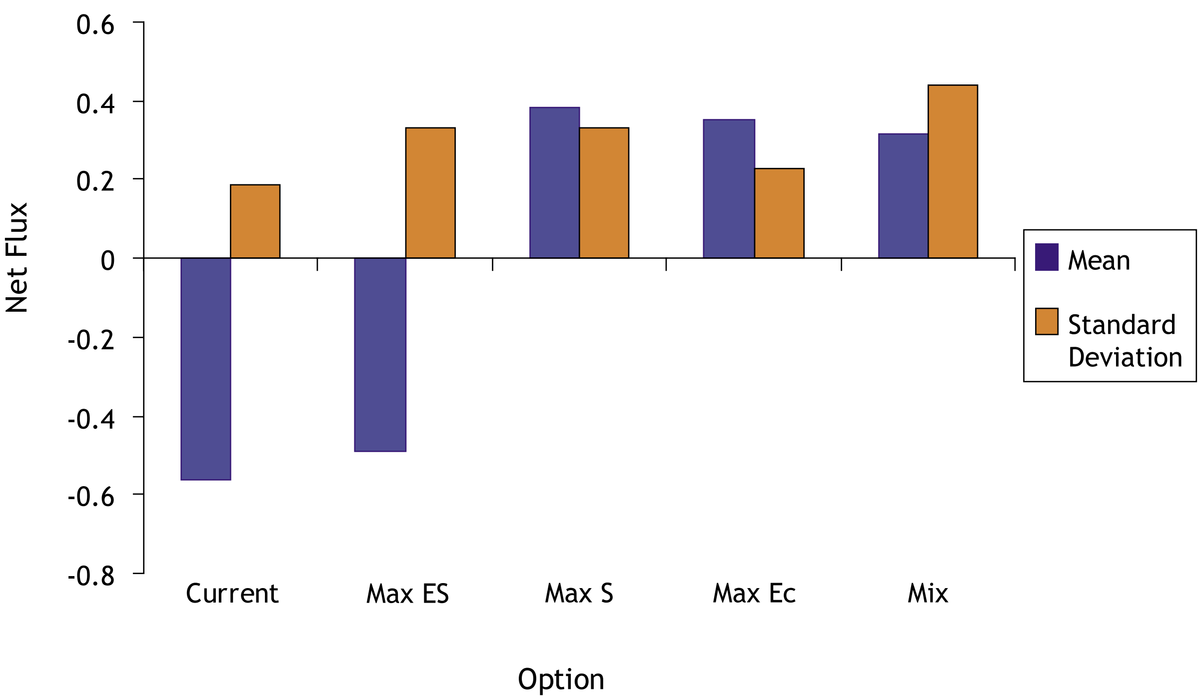
[3] This caused some amount of concern to the jury as the Sustainable Mix option (ranked third in the initial ProDecX run) is, in fact, the strategy which is about to be implemented in the Catchment and which is supported by the organisations that were represented by the jury members. The lower ranking of the Sustainable Mix option could indicate that it is lacking in the delivery of some outcomes ranked highly by the jury.

Figure 10.1 Ranking of criteria: where a value of 1 represents the highest rank and a value of 13 represents the lowest



Note: Each symbol represents a different juror.

Figure 10.2 Score and uncertainty of options prior to jury



The third witness, from a state natural resource management authority discussed issues concerning soil erosion. Those included the fact that road usage determines sediment production rates, where ninety percent of sediment runoff comes from roads and depends on the surfaces, age of road, soil type etc. The removal of vegetation from riparian zones also effects soil erosion.

Horses and off-road vehicles can be damaging users and the best management practices available to stem these effects include culverts and road surfacing. The total number of vehicles and horses as well as points of access (e.g. to streams) were also key considerations. An important point that was raised was the concern with the current lack of resources needed to manage these problems. One possible solution that was discussed was a levy on users in high-damage categories (e.g. four wheel drive vehicles). It was considered however, that political will was a fundamental requirement to impose such measures and greater research into providing incentives for solutions from markets and private firms was required.

The fourth expert (a member of the local parliamentary council) presented information on jobs and economic issues. He spoke of the bonuses to local jobs and industry resulting from recreation and tourism activities. Again the discussion reverted to public access issues and managing numbers and whether or not lessons could be learnt from other experiences with “user pays” schemes. Also identified was a need to measure the effects of public access on the riparian zones adjacent to rivers and streams (which in turn requires an exact definition of the extent of this zone). One question that was raised was whether or not it is possible to engage private landholders in recreation and tourism activities and, if so, if this would provide the experiences required by the public. Finally, the jury also agreed that the multiplicity of public land managers needs to be limited in some way.

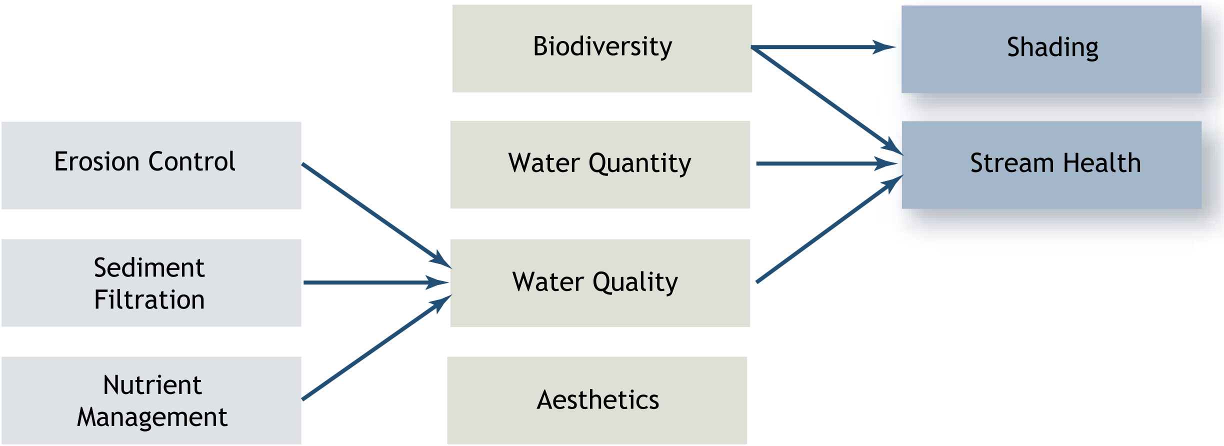
After the expert presentations, questions and discussions, the jury was asked to provide a weighting (as opposed to just a ranking) of the various assessment criteria to reflect each individual jurors priorities. Each juror was given one hundred cannelini beans each, with one third of the beans to be divided between the Ecosystem Services criteria, one third between the Social and Cultural criteria and one third to the Economic criteria. After the weighting exercise, the jurors and expert witnesses took part in informal discussions over lunch.

10.4.2 The Afternoon

The resulting criteria weights were fed into ProDecX and also graphed on a whiteboard so that all jurors could see each others positions. Those with outlying priorities were asked to defend their positions. The initial discussions revealed that the nine Ecosystem Services criteria could be limited to only four (Water Quality, Water Quantity, Biodiversity and Aesthetics) as these were all that were needed for the jurors to make decisions on recreation and tourism options. They argued that Stream Health is influenced by Biodiversity, Water Quality and Water Quantity. Shading is also influenced by Biodiversity and Vegetation Cover. Erosion control, Sediment Filtration and Nutrient Management determine Water Quality. Therefore the nine Ecosystem Services criteria can be adequately covered by just four: Water Quality, Water Quantity, Biodiversity and Aesthetics (Figure 10.3).

After the reassessment of the necessary Ecosystem Services criteria, the weighting exercise was again carried out and the results graphed on the whiteboard. Each broad criteria group was then discussed one at a time, with outliers identified and jurors asked to defend positions and whether they would vary them or not. As soon as a final position was agreed to, the weightings (Figure 10.4) were fed into ProDecX. The resulting favoured outcome was the Mix option (Figure 10.5). It can also be seen that the uncertainty has decreased considerably,

Figure 10.3 Causal links between ecosystem services criteria



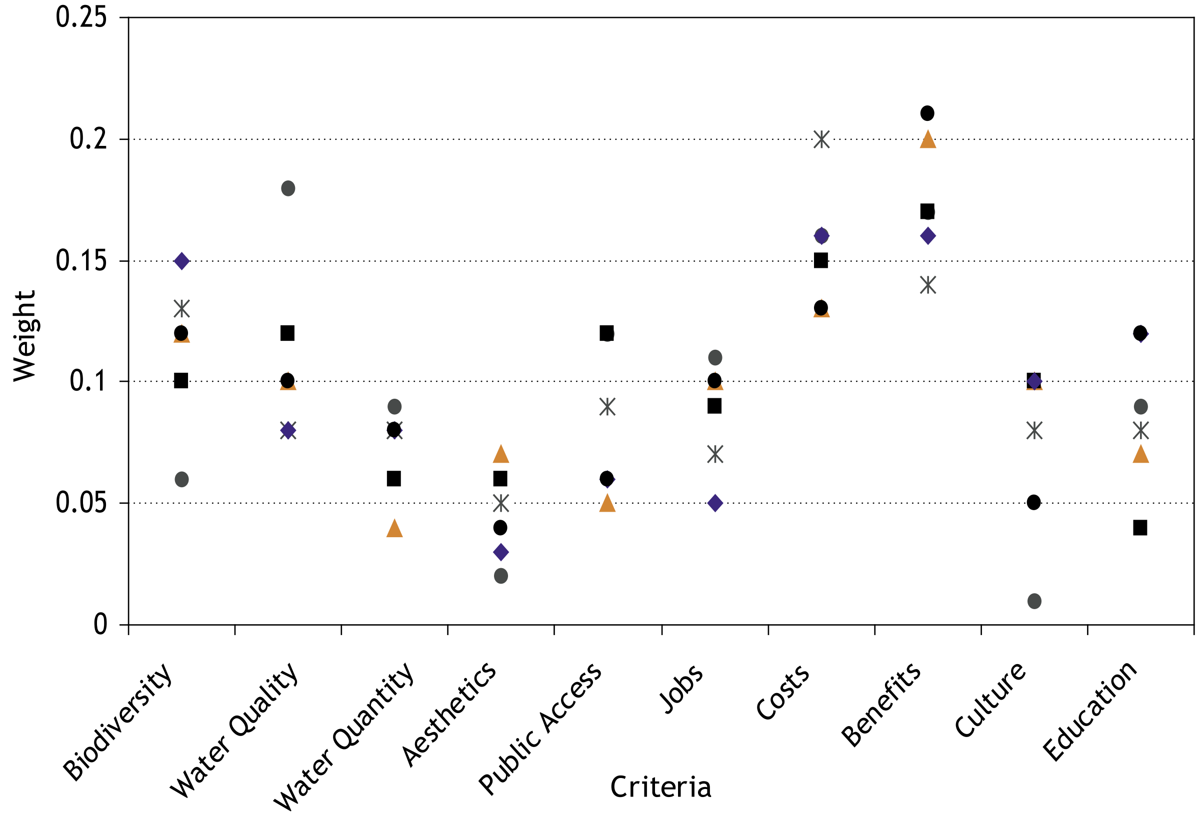
indicating that the ranking is now much more conclusive and consensus is much higher developed than before the start of the process.

10.4.3 Sensitivity Analysis and Discussion

A detailed sensitivity analysis was carried out after the jury process to further assess the decision problem. First the broad group weightings (agreed to by the jury to be 33 per cent for the ecological criteria, 33 per cent for the social criteria and 33 per cent for the economic criteria) were systematically varied. Next, some of the outliers found in the final weightings of the criteria were systematically fed into ProDecX. Neither of these tests had any impact on the overall ranking of the options.

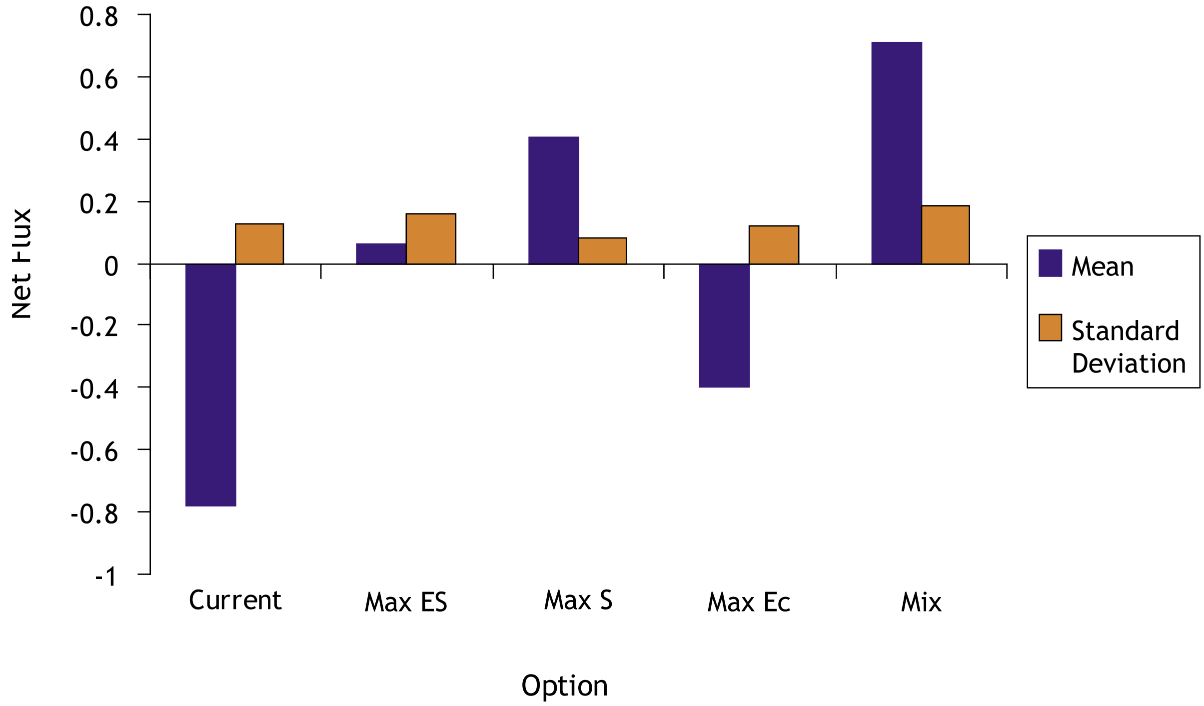
An analysis of the changes in the rankings of options after the jury process did reveal some important aspects of the procedure. Before the jury met and using a straightforward qualitative ranking (Figure 10.1) of the criteria resulted in an overall outcome of the Max S option being ranked first, Max Ec second and the Mix option third. The next run of the ProDecX software was done after quantitative weightings of the criteria were undertaken before and after the expert witnesses held their presentations. Furthermore, the jurors were asked to give the whole of all ecological criteria the same total weight as the whole of the social, as well as the economic criteria (1/3 for each criteria group) which had not been the case in the qualitative ranking in Figure 10.1. The main changes in the rankings of the options that occurred at this time were in greatly worsening the rank of the Max Ec option and greatly improving the position of the Max ES option. However, because of the various changes in the procedure before this step it is difficult to attribute causes to these different rankings (e.g. the effect of the expert presentations). The largest change to the overall rankings came when some of the Ecosystem Services criteria were dropped. This resulted in the Mix option being ranked first then followed by the Max S and then the Max ES options. Even after going through each set of criteria in turn to try and reach, as far as possible, a consensus on the weights, the overall rankings of the options did not vary much. The difference that was made was that the uncertainty measures were reduced.

Figure 10.4 Weighting of criteria



Note: Each symbol represents a different juror.

Figure 10.5 Final score and uncertainty of options



These findings mean that, in this particular instance, obtaining exact consensus on the weights of the criteria was not important as a range of weights (for each criterion) was sufficient to obtain consensus on a preferred option. However, of crucial importance was the process of each person defending their criteria weightings because of the important information that was revealed. For example, because of this process, jurors could in turn bring out the main issues that were important to them in choosing a criterion weight and, as it turned out, some of these legitimate issues had not been considered by some of the other jurors. For example, public access and the need to limit it was raised several times during the discussion and some methods such as entrance fees or surcharges on high impact recreational users were discussed but clearly more research and consideration is warranted. Another important issue that came out of discussions was the need for educating people on the importance of ecosystem services and whether or not a code of practice for tour operators to agree to could encourage them to educate tourists. Also from the findings, a critical part of the process was in determining the exact criteria to be considered and this only occurred after a significant amount of discussion by the jurors and experts that ultimately led to the simplification and non-duplication of the various Ecosystem Service decision criteria.

10.5 Conclusions

This chapter has detailed a method for aiding complex decision problems and applied this method to the problem of recreation and tourism management in the upper Goulburn Broken catchment.

The Deliberative Multi-criteria Evaluation of recreation and tourism options in the upper Goulburn Broken Catchment highlighted the importance of ecosystem services in recreation and tourism management, as well as the need for greater research on public access issues, the effects of education on tourists and environmental damage, methods for the recovery of management costs and the role of market and other incentives in limiting environmental damage of recreation and tourism activities.

In conclusion, the process identified to the decision-makers the importance of breaking down the decision problem and consequently being able to investigate the correct information to try and solve the problem. This involves asking the right questions at the start of the process and for researchers to know the priorities of the decision-making criteria and which of those criteria are important to measure. On the whole, the jurors found the process interesting, enlightening and enjoyable with the highlight for most of them being the revelation of different jurors' priorities and their defence of these positions. A question was raised, however, as to whether or not the process, in its present form, could be effective when citizens rather than natural resource managers are called on as jurors, and this remains to be tested. Of crucial importance though was the high priority placed on ecosystem services in the decision-making process related to recreation and tourism management.

11 Water inputs and nutrient outputs from the Goulburn Broken economy

11 Water inputs and nutrient outputs from the Goulburn Broken economy

Collaborators: Roel Plant, Jackie Robinson, Paul Ryan, Nick Abel

The aim of the case study is to demonstrate how the region's economy is linked, via water use and nutrient pollution, to services provided by regional ecosystems.

11.0 Case study highlights

Project outputs include:

- an input output model that tracks the movement of dollars, water and nutrients among 33 different sectors of the catchment economy.

Key observations from the workshop and analysis are:

- the dairy processing industry has the largest influence on the regional economy for each dollar invested in the industry;
- the 'other horticulture' sector has the largest regional influence on water use for each dollar invested in the industry;
- the framework allows simultaneous evaluation of investments in regulation of groundwater levels and river flows, maintenance of stream health, and the importance of industries in the catchment; and
- environmentally extended input-output analysis is an insightful and elegant top-down instrument that provides solid underpinning of policy decisions.

Key considerations are:

- accurate, consistent and recent data are essential.

11.1 Introduction

Ecological processes in catchments provide the ecosystem services of regulating water flow and quality (sections 8 and 9). The regional economy of the Goulburn Broken Catchment is heavily dependent on the continued supply of water of a suitable quality and sufficient quantity in order to maintain regional wealth (State of Victoria, Victorian Catchment Management Council 2002; Goulburn Water Quality Working Group 1996). With the Goulburn Broken Regional Catchment Strategy as a guiding principle, rural landholders, in partnership with government are currently investing between 30 and 40 million dollars per year in farm infrastructure, particularly in the Shepparton Irrigation Region (SIR). These investments aim to achieve increased production and better protection against land and water degradation, mainly through improved water use efficiency. This is essentially a bottom-up approach, driven by the current on-farm physical soil conditions and focused on safeguarding current levels of agricultural production.

An alternative way to look at water use efficiency is to link water use with sectoral economic transactions in an input-output model. This economic analytical framework employs a top-down approach and analyses water use in terms of economic output and, if desired, other factors. Consequently, an input-output model can identify alternative sectoral distributions of final demand that maximise a region's total economic output with the currently available water resources. The analysis can be extended by adding additional constraints and optimisation objectives (e.g. by capping stream nutrient pollution and/or maximising employment).

Investments in the permanent transfer of irrigation water entitlements from low dollar output to high dollar output farming enterprises provides a permanent stimulus to the gross regional product from that water. Input-output analysis can support policy decisions regarding adaptive initiatives in water management like transfer to more profitable users and less water-stressed regions, water pricing and trading, and increases in water use efficiency.

The overall aim of this case study was to provide a comprehensive snapshot of the current catchment economy and ecology by linking the regional economic structure with the use of water and the generation of stream nutrient pollution in an input-output model. The Catchment Management Authority and others may use the model outcomes to explore the consequences for employment, income, and gross regional product of various scenarios of water use and availability. In this context, scenarios are defined in terms of different combinations of objectives (e.g. maximise employment) and constraints (e.g. minimise stream nutrient pollution). Examples of questions that may be answered are: 'what if the dollar value of output from a sector (or sectors) change(s)?'; 'how much can the value of output grow given the current water use?; and 'what is the impact on employment of switching water use into sectors that produce a high dollar value per ML of water?'.

11.2 Methods

11.2.1 The general input-output framework

The purpose of input-output analysis is to analyse the interdependence of industries in an economy; the input-output tables, which are central to the framework, allow detailed analysis of the process of production and the use of goods and services (products), and on the income generated in that process.

An input-output model consists of an inter-industry (or inter-sectoral) transactions table from which factor multipliers are derived using linear matrix algebra. The transactions table holds information on monetary flows in terms of total sectoral output. A factor multiplier matrix can be calculated from a matrix containing sectoral production factor usage information (e.g. employment and water use).

11.2.2 Input-output solutions and multipliers

The notion of multipliers rests upon the recognition that activities exogenous to the local economy (e.g. increased export activity) have an amplified effect on the rest of the economy, triggering cycle after cycle of local spending that puts people to work in locally oriented economic activities. For each dollar injected in the local economy, local residents may earn more than one dollar as those dollars move from one locally oriented business to another. The first dollar earned is the so-called initial effect, and the additional dollars earned are known as the flow-on effect. The total effect (total multiplier) can be defined in either of two ways: 1) as the direct and indirect effects, or 2) as direct, indirect, and induced effects. Multipliers that capture the direct and indirect effect are known as simple multipliers (Type I), whereas total multipliers represent the direct, indirect and induced consumption effects (Type II).

Income and employment input-output multipliers show responses to an output stimulus in the conventional form. In general terms, multipliers can be deployed for any item which can be assumed to be directly and linearly related to output levels. An example of the calculation and use of water multipliers at the national scale is given by Lenzen and Foran (2001).

Although the multiplier approach to impact measurement is straightforward, it is important to keep in mind the limitations of the approach (Power 1996). Firstly, the increase in the value of output should not simply be due to an increase in product price levels that are not reflected in increased usage of physical inputs. Secondly, the increased production should not simply be an aberration due to climatic conditions affecting physical output without affecting the purchase of inputs. Only if the change is a genuine expansion or reduction of the industry in terms of inputs and outputs should this approach be used for impact assessment. Thirdly, the input-output equations are assumed to apply equally to increases and decreases in output. In practice, the process of contraction is usually not a mirror image of the process of expansion, so some caution is required before generalising from expansion to contraction situations.

11.2.3 Extending the input-output framework

The key issue in economic-ecological models is to trace the relevant interactions between the economy and the environment and to examine how policy alternatives modify the two-way flow processes (Ayres and Kneese 1969). When evaluating environmental issues we can distinguish between factors viewed as inputs to an industry production process (e.g. water, energy, employment) and those factors viewed as outputs generated by that production process (e.g. air pollution) in a broader, non-monetary sense (Miller and Blair 1985; this report Section 4.2). Natural assets and non-market outputs like water and air pollution often have non-market values, so the valuation of their use and disposal in an economic context can be difficult.

Because of its nature, the input-output analytical framework has long been recognised as well suited to cover both human-made (economic and social) and natural assets (Isard and Romanoff 1967; Leontief and Ford 1972; Duchin and Lange 1994). Therefore, the history of economic-environmental models building upon Leontief's basic definition is long (Forssell and Polenske 1998; Forssell 1998). Nevertheless, the problem of non-comparable units has long been central when extending the input-output framework. A straightforward solution is to augment the transactions matrix with rows and columns representing pollution generation and/or abatement coefficients. The added rows hold information regarding the amount of a resource used (water, pollution abatement) per dollar's worth of industry output, and the columns reflect the amount of pollution generated per dollar's worth of industry output.

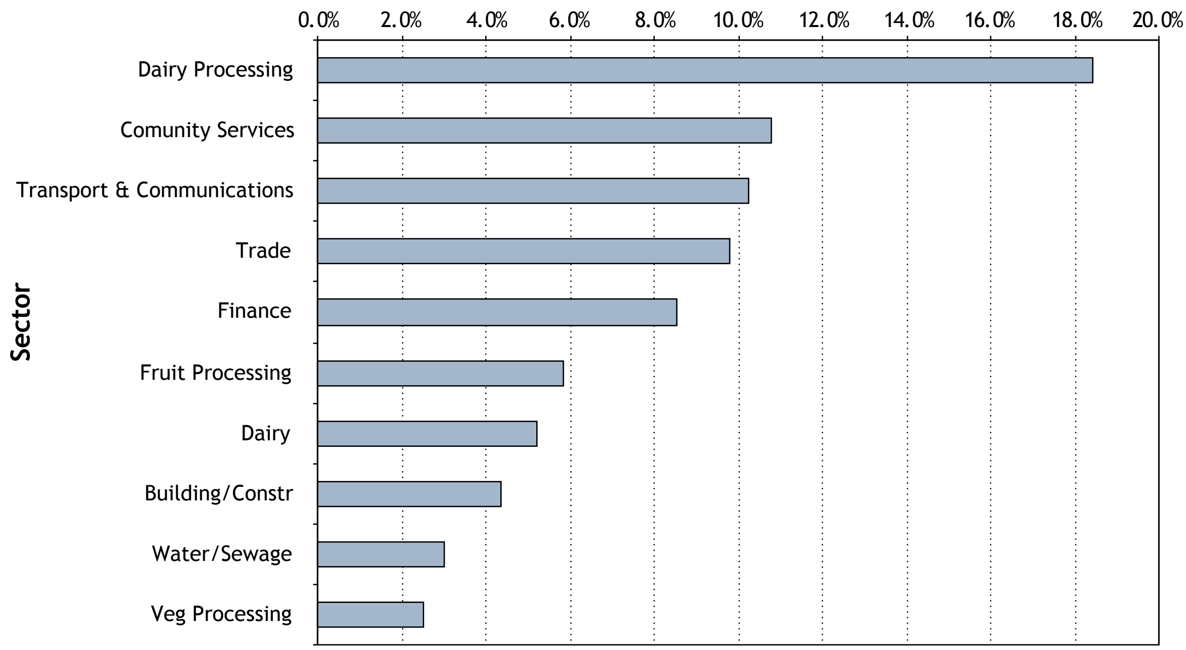
11.3 EconomIc and biophysical data

11.3.1 The transactions table

For the purpose of this analysis, the region of interest encompasses the Goulburn-Broken Catchment in Victoria, which includes the local government areas of Moira, Campaspe, Shepparton, Mitchell, Delatite, Murrindindi and Strathbogie. Economic activity in the catchment was organised into 33 industry sectors categorised according to the Australia, New Zealand Standard Industry Classification (ANZSIC).

A combination of survey and non-survey data were used to collate the 2001 transactions table for this region of interest. First, published data from the Australian Bureau of Statistics (ABS) were used to estimate the total dollar outputs for a number of agricultural and manufacturing sectors. Second, a field survey was conducted in the Goulburn Broken Catchment to collect additional information on sources of inputs and destinations of outputs at the catchment level. Results from the field

Figure 11.1 Relative contribution of the ten largest sectors to total dollar value of output



survey assisted with the disaggregation of a number of manufacturing sectors located in the catchment and deemed individually relevant for this particular study. Non- survey data were used to construct a number of additional sectors. This involved proportioning the output and structure of national industries to a regional scale using location quotients. For the most part, this approach is adopted for service industries about which there is minimal local data available. The catchment-scale technical coefficients were estimated using similar input proportions as indicated in the national input-output table.

The resulting inter-industry transactions table for 2001 distinguishes 33 sectors. Total gross value of production in 2001 was $ 8,709 M. This figure is consistent with the $ 7,800 M and $ 9,620 M estimated for the years 2000 and 2005, respectively, by Young (2001). Figure 11.1 gives the relative contribution to total regional dollar output for the ten largest industries.

In 2001 there were 80,446 jobs in the catchment; 20 percent of these were in the trade sector, 16 percent in community services, and 9 percent in tourism. The largest industry in terms of dollar output, the dairy processing sector, provided 6,805 jobs (8.5 percent of the total jobs).

Industries within a sector are assumed to be homogeneous. This means that, for example, all firms classified as "dairy" are assumed to have similar purchasing patterns. In estimating the purchasing patterns of firms within an industry sector it is not feasible to interview all individual firms in the industry. The rationale of the "representative firm" is adopted which means that the modelling of the structure of an industry within the input-output model represents that of an average firm; not so large that it dominates the industry but not so small that it is atypical of firms in the industry.

11.3.2 Water use data

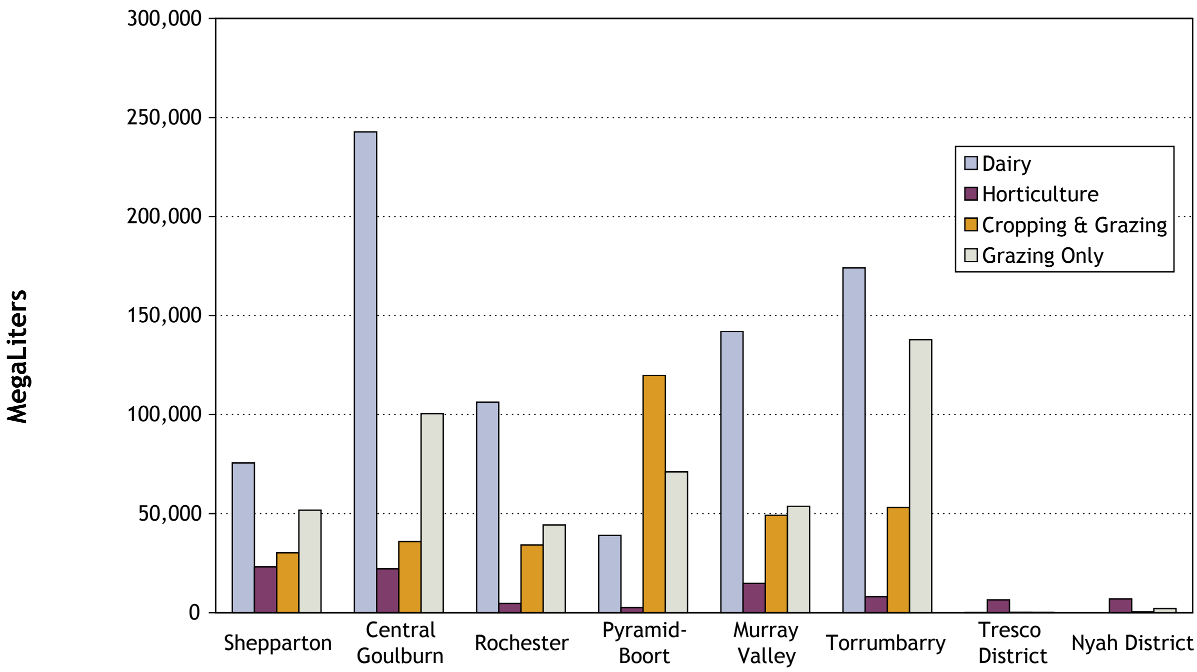
Since the transactions table [A], the 'engine' of the input-output framework, is an empirical representation of the economic-ecological status of a region for a given slice of time, it is important that the various data sources share the same time domain. Sectoral water use data were derived from the Farm Irrigation Survey 2000/2001 (Goulburn-Murray Water, unpublished data). The water accounts for Australia 1993–94 to 1996–97 (McLennan 2000) were not helpful because they don't provide regional breakdowns of the water use figures. Because domestic and industrial water use accounts for only 3% of the total water use in the catchment, only the water used in irrigation farming was considered.

Total water use was 995,280 megalitres (ML), of which 70 percent was used in dairy farming, 15 percent in the grazing sector, and 10 and 5 percent for mixed cropping/grazing and horticulture, respectively (Figure 11.2).

11.3.3 Stream nutrient pollution — nitrogen and phosphorus

To exemplify the use of additional environmental criteria, stream nutrient pollution data were added to the transactions table as columns. Surface runoff is the main transfer mechanism from irrigated pastures in the Goulburn Broken catchment, making those pastures the main diffuse pollution source. Stream nutrient pollution related to sectoral economic activity was estimated based on an inventory of typical total phosphorus (P) and nitrogen (N) losses in surface runoff and in discharge from catchment point sources (Nexhip 1999). Nexhip distinguishes five irrigated land uses: perennial pasture, annual pasture, crops, vegetables, and fruits. All P and N losses from perennial pasture were attributed to dairy farming. Additional amounts of 7.3 tonnes (T) P per year and 56.3 T N per year were added to the dairy farming sector to account for shed effluents (a point source).

Figure 11.2 Water use [megalitres] by industry and region, 2000–2001



	Shepparton	Central Goulburn	Rochester	Pyramid-Boort	Murray Valley	Torrumbarry	Tresco District	Nyah District
Dairy	75,641	242,714	106,318	39,032	142,005	174,076	52	0
Horticulture	23,162	22,165	4,625	2,603	14,817	8,105	6,445	6,943
Cropping & Grazing	30,236	35,863	34,217	119,781	49,194	53,111	166	438
Grazing Only	51,785	100,458	44,322	71,094	53,724	137,776	129	2,039

Also, 0.6 and 2.8 T of P and N per year, respectively, were assigned to the intensive animal-farming sector.

11.3.4 The shepparton workshop

The effectiveness of the input-output model largely depends on having realistic input data and a recognition of envisioned users as to possible applications. Therefore early feedback from experts and catchment community members with knowledge of particular industries was obtained during a workshop held in Shepparton on March 13, 2003. The two main agenda items were 1) the quality of the economic and biophysical data used and possible additional data sources, and 2) the stakeholder's views on how the input-output model may be applied to the natural resource management issues in the Goulburn Broken Catchment.

Also, participants were asked to give their opinion on possible trajectories of economic change for each sector. Figure 11.3 shows the changes upon which the participants agreed for the ten largest industries. The established bandwidths can be used as constraints when optimising for one or more objectives (e.g., maximise output and minimise water use).

11.4 Results

Figure 11.4 gives the top five total output and income multipliers. The dairy processing sector has the highest output multiplier. The value of 2.42 implies that for each dollar injected in this sector local residents may earn 1.42 additional dollars as the dollars move from one local business to another.

Figure 11.3 Estimated likely future change [%] for the ten largest industries (by dollar value of output)

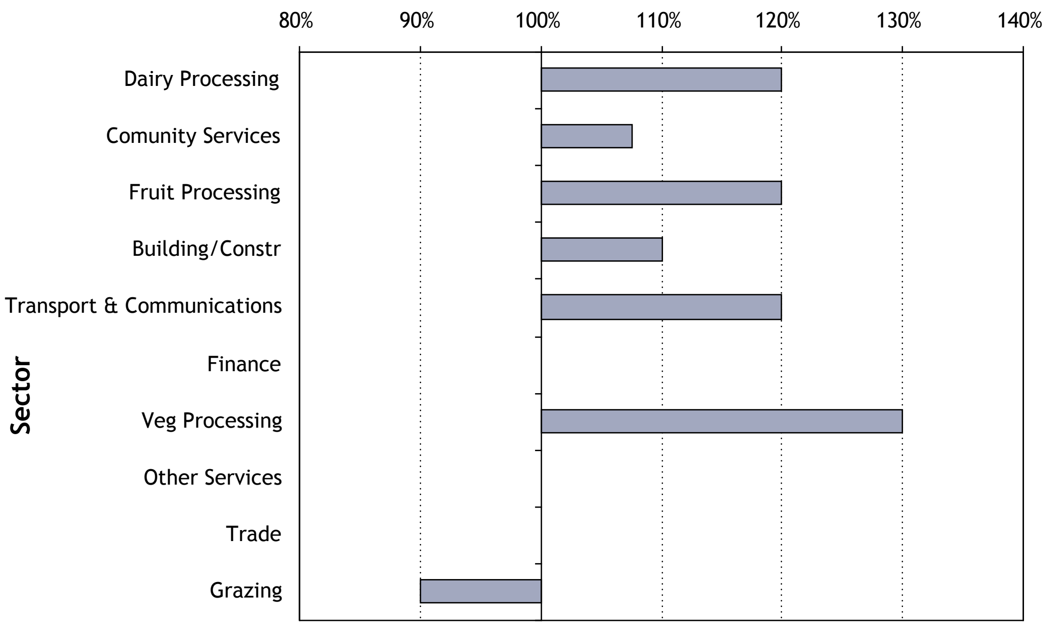


Figure 11.4 Output multipliers and employment multipliers

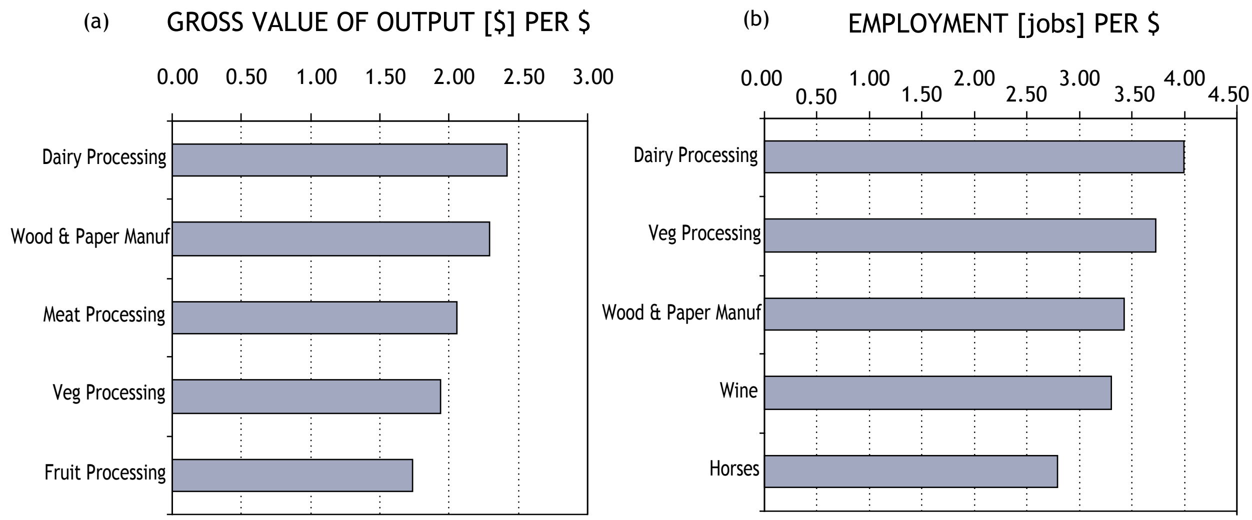
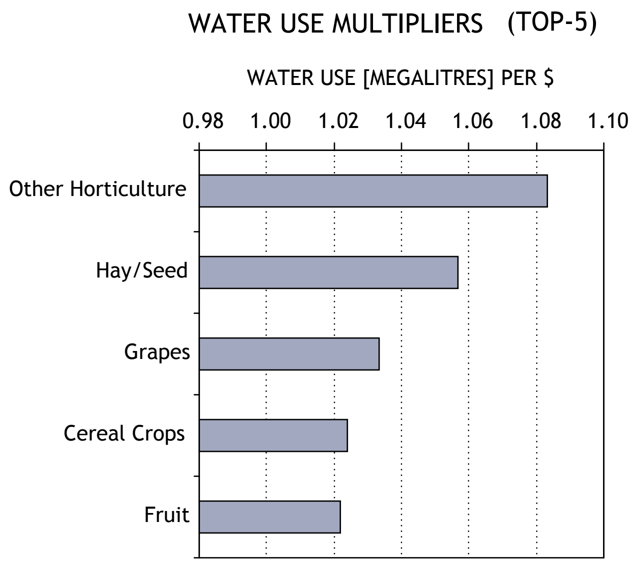


Figure 11.5 gives an indication of the differences of water multipliers for the top five economic sectors. A water multiplier of 1.1 ML per dollar ('other horticulture' sector) indicates that an increase of one dollar in demand for products of this industry eventually leads to an extra demand for 1.1 ML of water.

The bandwidths established during the Shepparton workshop were used in an explorative optimisation exercise (Duchin 1992). A very common application of input-output analysis is to perform an impact analysis (Jensen and West 1986). Impacts are measured in dollar output terms, and the impacting agent may be an actual or potential source of economic change in the economy in question, or an industry that is currently established and operating in the economy.

The impact simulated was a "reshuffling" of outputs across the various sectors to maximise the output per ML of water. This optimisation may lead to unrealistic outcomes,

Figure 11.5 Water use multipliers



i.e. the attribution of all economic activity to sectors that, according to the input-output model, do not use water. Therefore, any optimisation must be constrained by allowing sectoral outputs to change within a limited domain. These domains were set using the bandwidths derived from the workshop.

Table 11.1 illustrates the interpretations that can be made based on a reshuffling of sectoral outputs within reasonable boundaries. With the current (2001) output level of $ 8,709 M, total water use is 995,280 ML, and there are 80,446 jobs in the catchment. With worst-case economic growth — as predicted by the expert panel during the workshop — output increases to $ 9,219 M, whereas the total number of jobs increases and the water use decreases, albeit slightly. This indicates that in this scenario growth is predominantly taking place in the less water-intensive sectors with employment multipliers that are relatively high. With best-case economic growth both output and jobs increase, but the water use to support this level of economic activity is much higher (over 1 M megalitres) than that under the current level of output.

If the water use is constrained to the 2001 level (995,280 ML), and output levels are reshuffled using a linear optimisation for output, both output and jobs increase, which means the overall water use efficiency has increased. Perusal of the relative changes of output levels across sectors shows that under this scenario the fastest growing sectors are the fruit processing sector (1.8 percent), the community services sector (1.3 percent) and the transport and communications sector (1.2 percent). The outputs of the dairy and vegetables processing sectors remain constant, and grow by 1.1 percent, respectively.

Table 11.1 Summary results for three different economic growth scenarios

	Current Output Level	Worst-Case Econonomic Growth	Best-Case Econonomic Growth	Maximum Output with Current Water Use
OUTPUT [$ M]	8,709	9,219	10,655	9,787
INCOME [$ M]	1,117	1,182	1,350	1,261
EMPLOYMENT [jobs]	80,446	80,684	100,543	94,140
WATER USE [ML]	995,280	993,081	1,141,540	995,280
P-POLLUTION [T]	1,212	1,216	1,401	1,222
N-POLLUTION [T]	2,161	2,158	2,488	2,181

11.5 Conclusions

The input-output analytical framework provides an elegant top-down instrument to investigate the most efficient use of water resources in a region. Accurate and recent data are essential and when this requirement is met, results from an economic-ecological input-output model provide a solid underpinning of policy decisions. Our optimisation example only illustrated how the water resources in the Goulburn Broken can be used more efficiently in terms of output, but other optimisations are possible. For example, the stream nutrient (N and P) pollution may be capped at their current levels and additional requirements as to employment growth may be added.

If the (non-spatial) distributions of water use and nutrient outputs can be converted to a spatially explicit representation based on land use, the framework can be used for the simultaneous evaluation of investments in ecosystem services (regulation of groundwater levels and river flows, maintenance of stream health), and the importance of industries in the catchment.

12 Achievements, findings and recommendations

12 Achievements, findings and recommendations

In this section we describe achievements, findings and recommendations framed against the project objectives.

12.1 OBJECTIVE: Communicate project results widely

12.1.1 The ecosystem services concept is now in the vocabulary of agencies, land managers and politicians

Our communication has been highly effective. The ecosystem services concept has entered the vocabulary of agencies, land managers and politicians and is being used in plans and policies at local, state and federal levels. Feedback from key policy makers confirmed we were directly responsible for raising awareness of the concept in their organisations, where it is increasingly referred to as 'environmental services'. We can claim some credit for the fact that the term appears in major state and federal environmental policy and discussion papers.

The Bureau of Rural Sciences is establishing an ecosystem services unit to assess services at national scale. The New South Wales Environmental Services Scheme is operating at 27 sites across the State in its investigation of market and other mechanisms for sustainable use of services. A new $5 million 'Markets Based Instruments' (MBI) initiative has been launched by the Federal government to establish on-ground projects to test a variety of mechanisms for sustainable use of ecosystem services. Ten MBI pilot projects, located in Queensland, New South Wales, Victoria, South Australia and Western Australia, are now in place, studying mechanisms such as auctions for ecosystem services, tradable water table recharge contracts, leverage funding, an insurance scheme, offsets and cap and trade. Our group is involved in three pilot projects. Other ecosystem services projects proposed or started include: the Bet Bet Landscape Renewal Pilot Project; the South Australia Competitive Tendering for Ecosystem Services Project; Local Incentives for Conservation; Monitoring and Assessing Investment in Native Vegetation Protection and Restoration; Public-private Investment Partnerships for Afforestation; and Carbon Sequestration, Climate Change, and Catchment Salt and Water Balances.

We cannot claim these would not have happened without our project, but we are confident our communication activities have helped create a policy, funding and intellectual environment in which ecosystem services projects are treated much more favourably than they would have been in 1999. Our Goulburn Broken work was directly responsible for ecosystem services becoming a central theme in the 2003 draft of the Goulburn Broken Regional Catchment Strategy. Agencies are introducing the concept to landholders, who relate readily to it, and it is used by other Catchment Management Authorities/Boards.

12.1.2 We have built a national and international research network

We have built links with ecosystem services researchers in Australia, New Zealand, the US, Germany, Switzerland and South Africa. We have held four scientific workshops with collaborators. We hosted ecosystem services symposia at the annual conference of the Ecological Society of Australia in 2000 and 2002. We have developed good collaborative links with other CSIRO divisions and a range of agencies and consulting firms. Team members have given conference papers or attended workshops on every continent except Antarctica. Publications include the companion volume to the present report, Natural Assets: An Inventory of Ecosystem Goods and Services in the Goulburn Broken Catchment (Binning and others 2001). This has been in high demand with almost 1500 copies distributed. An issue of L&WA's River and Riparian Lands Management Newsletter, RipRap (Feb 2002 Vol 21), featured Ecosystem Services (http://www.rivers.gov.au/publicat/riprap/riprap21.htm).

12.1.3 The ecosystem services website is spreading awareness of ecosystem services among the broader community

The communication strategy of this project has promoted the sharing of knowledge among researchers and other members of society, and encouraged broad dialogue about the value of Australian environments to people. It has done this through newsletters, presentations (to a range of state and federal policy and land management agencies, at public meetings in the Goulburn Broken and other catchments, and at conferences around Australia), leaflets and papers. The project website (http://www.ecosystemservicesproject.org/) is a major avenue for communication. Through it we provide information on other projects and case studies, recent publications and new developments. There is a feedback form for comments and an electronic newsletter distributed via email. Website hits have increased from 200 a month after the website was launched in 2002, to the current level of about 1000 a month.

12.2 OBJECTIVE: Work with policy makers, planners, land managers, industry and community groups to raise awareness of the values of maintaining ecosystem function

12.2.1 Participatory research enhances the sharing of ideas and knowledge about ecosystem services

Participatory research enabled researchers i) to identify key issues that policy makers and land managers face, ii) to focus on ways in which scientific research can help to address these issues, and iii) to adapt the concept of ecosystem services for this purpose. Through this participation, the concept of ecosystem services has become well known in the major organisations in the Goulburn Broken Catchment and regional environmental and primary industries agencies. In many cases, these agencies have further adapted the concept for their purposes.

12.2.2 A participative process guides the direction and scope of the research and enhances learning

Each case study included a participatory element through which scientific and local knowledge were exchanged, modified and combined. The direction and scope of the case studies and the project as a whole were also guided through this exchange. Thus there was a strong learning element in the project as a whole, but the recreation and tourism case study was designed with stronger learning objectives than the other studies (Section 10). The deliberative process, with opportunities for debate, reflection and feedback is a model for further participative studies.

12.2.3 Understanding about, and willingness to act on, the values of ecosystems appears to be increasing among land managers and policy makers

The enthusiasm of the partners in the project has contributed to raising awareness and understanding of the processes that occur in ecosystems and the benefits they provide. The partnership was directly responsible for ecosystem services becoming a central theme in the recently revised Regional Catchment Strategy (Goulburn Broken Catchment Management Authority 2003). Agencies are introducing the concept of ecosystem services to landholders, who in our experience relate readily to it. It is used by other Catchment Management Authorities/Boards and complements the 'natural assets' concept already in use.

While the concept of ecosystem services is useful in increasing understanding of environmental issues and channelling dialogue towards solutions, it is only one progressive force among many. People and organisations in the Goulburn Broken catchment have a long history of re-conceptualising environmental challenges in ways that involve the public in solutions, and our project rode, to some extent, on the back of those earlier initiatives. It remains to be seen how well an approach such as ours would work in a catchment that lacks a high degree of agreement about issues, commitment to seeking solutions through collaboration internally and externally, and willingness to test new approaches and concepts such as ecosystem services. The ecosystem services project in the Gwydir catchment of New South Wales will provide some insights.

12.2.4 Generating stakeholder enthusiasm to value ecosystem services needs to be balanced against the capacity of researchers to estimate those values

The communication of the concept of ecosystem services raised great expectations of the project, which we attempted to contain to a level we could satisfy. The original proposal aimed to implement four case studies of the magnitude of the Goulburn Broken study and produce a map of the status of ecosystem services nationally. The Myer Foundation, CSIRO and Land & Water Australia, encouraged the ambitious scope of the project. This scope was later reduced to a set of pilot projects, one in the Goulburn Broken catchment, one in the NSW rangelands, and one in the tropical forests. Other ecosystem services research activities in the Gwydir catchment of NSW and in New Zealand were linked to the Australian Ecosystem Services project through the network that the grant from The Myer Foundation funded, but their research was primarily funded from other sources.

In our communication and relationship-building with project partners, we explicitly recognised that neither the budget nor the knowledge available would allow the scientists to produce highly accurate or precise models of ecosystem function or to make meaningful estimates of value (economic or otherwise) for all ecosystem services across even one case study. This was well understood by the partners on the Goulburn Broken Catchment.

Our communication via the media to a broader audience unintentionally raised the expectation that we intended to value Australia's ecosystem services and to do so in their entirety. Our efforts to engage as many people as possible in thinking about the issues meant that the communication activities gained significant momentum. Enthusiasm was developed among a range of partners, including many researchers, and led to the establishment of eight research projects around Australia. Two other divisions of CSIRO established research priorities around ecosystem services. Meanwhile our own research team was still grappling with the theoretical and methodological content of the ecosystem services concept, and the challenges of forming a multi-disciplinary team. Consequently communication, including community engagement, moved ahead of research, so realistic expectations for the project had to be negotiated later on.

We have learned that managing expectations among stakeholders and researchers is important, and how to do it. The advice of the catchment partners, their involvement in the Inventory process (Section 6), and some open dialogue about the individual capacities of the research team and the brevity of the project led us to base the research on the five case studies, which this report shows was a feasible and useful approach.

12.2.5 It will take much more than changes in attitudes to achieve sustainability

There is an expectation of the ecosystem services concept that it will lead to national and regional sustainability through changes in attitudes. It is not that easy. The same expectations were placed upon the concept of ecologically sustainable development in the 1990s. The Federal Ecologically Sustainable Development Policy has not been a panacea, and ecosystem services will not be either. Reversing ecosystem degradation will be a political economic process requiring changes in the distributions of benefits and costs within and across generations. We expect the concept of ecosystem services to play an informing role in this process, helping stakeholders to understand their relationships with nature, but to achieve sustainability people must also change their relationships with each other through institutional reforms, and meet their obligations to future generations.

12.2.6 Research partnerships need trust

We took time at the beginning of the project to develop trust among partners. We began with a workshop in which expectations of all parties were explored and documented. It was reinforced by a Relationship Agreement and by equal representation and shared authority on the project Steering Committee. The individuals originally involved in setting up the partnership committed themselves to seeing the project through to completion. This was vitally important because a common reason for lack of trust in such studies is suspicion that one or other partner will disengage if their political or financial imperatives and pressures change.

During the project there were changes in key staff in the research team and Catchment Management Authority. There were also major changes in political and financial pressures for all partners. It is a particularly important aspect of this project that these pressures did not undermine the trust relationship and that all partners remained committed. This is testament to the integrity of a number of key individuals among the partners and the willingness of new partners to respect and renew prior commitments.

12.3 OBJECTIVE: Estimate the benefits of ecosystem services at a range of spatial and temporal scales as a way to help policy makers, planners and land and water managers take account of the inter-relationships among a range of ecological, economic and social values

12.3.1 Ecosystem services need to be carefully defined

Careful definition of ecosystem services is critical to the subsequent analysis of underlying processes and interpretation of their values. In our approach stakeholders defined the services to ensure the relevance of the services to their goals, and to make sure the services were communicated in a way that was understood by the community. However, multiple stakeholders reinterpret the intended meanings, so original definitions can come to mean different things. A description of the service and its context and purpose is needed to ensure the original meaning is retained and conveyed to researchers and others. This is important because as shown in the case studies the analysis of the services is carried out at the level of the underpinning biophysical processes. Without the context, researchers could easily interpret the meaning of a service based on their own experiences and choose the wrong set of biophysical processes to analyse.

12.3.2 There is a range of ways to express ecological, economic and social values

This report focussed on the production and roles of ecosystem services, rather than users' perceptions of their values, so it was appropriate to represent ecological, economic and social values using different units, rather than lose information by expressing them as a single unit (Section 4). The dryland catchment study used bio-physical units. In the dairy and floodplain studies we brought ecosystem services and outputs such as soil and nutrient losses expressed in bio-physical units together with gross margins in dollars.

The evaluation of recreation and tourism in the upper Goulburn Broken Catchment showed how a deliberative process linked with multi-criteria evaluation can be used to quantitatively integrate values expressed in different terms and units. For example, under different management options, economic costs could be compared with the presence/absence of various outcomes and stream flow. This is especially relevant for the upper catchment where human aesthetic values are being traded against production losses. But it is also important for our understanding of ecosystem services where value cannot always be expressed in dollars.

In the whole-of-catchment input-output analysis our units were numbers of people employed as a measure of social value, mega-litres of water as a measure of the ecosystem service input, sector outputs in dollars and tonnes of nitrogen and phosphorus as negative impacts on ecosystems.

12.3.3 The dairy case study illustrates the dependence of high intensity enterprises on ecosystem services provided from a broader scale

The dairy case study has identified the need for better understanding of the contributions of soil organisms and native predators to pasture production. It reinforced the need, already recognised by the industry and the Catchment Management Authority, for more effective ways of capturing and recycling nutrients because of their negative impacts on other ecosystem services. A significant finding was, however, the relatively low priority of on-farm ecosystem services in this intensive system. At a broader scale of course dairy farms depend on ecosystem services for regulating and purifying flows of irrigation water, balancing carbon outputs, capturing the nutrients that escape the farm, producing fodder and shade for dry cows, and supplying nutrients and moisture for growing crops used for supplementary feed. The floodplain and sub-catchment case studies analyse these broader scale services, but the key point is that the dairy farm could not continue to function if its external supplies of ecosystem services fail. The dairy industry is a source of much of the region's income (Section 11) so there is a strong economic argument for investing in natural capital at the broader scale, and for linking the benefits of dairying to the costs of maintaining their ecosystem services.

12.3.4 The inclusion of ecosystem services may increase the net social benefit of changing management regimes

The benefit-cost ratio of changing the flows across the lower Goulburn floodplain has been estimated as 1.78 using a discount rate of 4% (Goulburn Broken Catchment Management Authority 1998). Our floodplain model still awaits flood input data, but once operational it will estimate the contribution that redirecting flows will make to changes in pasture, livestock and crop production. It will also estimate changes in carbon sequestration, the maintenance of native vegetation types and habitat, for native species and water filtration. These ecosystem services were not included in the existing benefit-cost analysis (Goulburn Broken Catchment Management Authority 1998) and may represent a significant increase in the net social benefit of the scheme. The approach is generic and can, in principle, be applied to the extensive floodplains of the Murray Darling Basin.

Our sub-catchment case study illustrates a related point — the ecosystem services provided by the sub-catchment under a different vegetation cover may be more valuable to the whole catchment than the value of the current agricultural outputs. The net income per hectare from this extensive agricultural area is small compared with that from a dairy enterprise, yet as we discuss in section 12.3.3, the dairy is dependent on the broader catchment for its ecosystem services. This points to the potential of markets or other mechanisms through which land holders produce ecosystem services that support the functioning of the Goulburn Broken Catchment as a whole.

12.4 OBJECTIVE: Evaluate the ecosystem services concept

12.4.1 The ecosystem services concept provides a framework for integrating research across disciplines and among policy makers, stakeholders and researchers

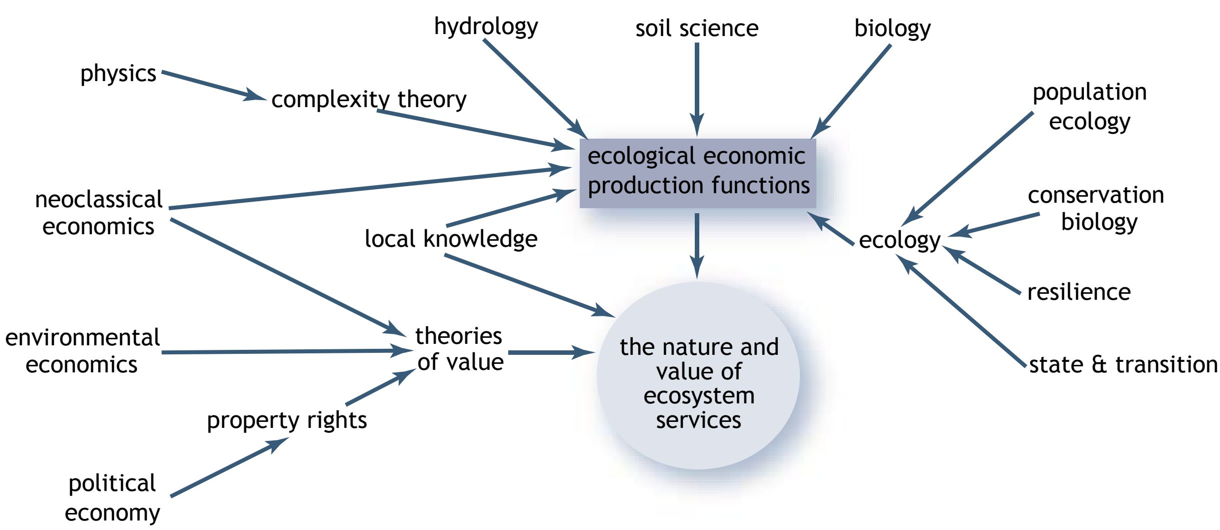
The ecosystem services concept enables local and scientific knowledge to interact to their mutual enhancement. In addition to this exchange of ideas, local knowledge guides researchers towards work that has practical use.

The ecosystem services concept brings disciplines together under a common theme to facilitate better interaction among scientists. Figure 12.1 includes the range of disciplines that have interacted in the course of this project, during which we have built transdisciplinary bridges. Figure 12.1 includes some disciplines that were not involved in the Goulburn Broken research but are becoming involved in the markets for ecosystem services work and other new projects (Section 13).

Ecosystem services research involves researchers from a wide variety of disciplines, and not all of them will see equal value in the concept. To many, the message that humans depend on ecosystem services for their survival and well-being is no more than a truism. However, the Inventory process (Section 6) provided our team with problem areas around which we could develop research questions, after which the researchers' curiosity and problem-solving skills provided their own momentum. Thereafter ideas and methods sprang from disciplinary theories and researchers' pre-existing knowledge and skills. These were integrated within the inter-disciplinary forum the ecosystem services concept provided.

One of our ideas can be attributed directly to the ecosystem services concept itself — the proposed functional approach to prioritising ecosystem services (Section 12.5.2).

Figure 12.1 Disciplines and theories contributing to the ecosystem services concept



12.5 OBJECTIVE: Develop and test methods

12.5.1 Enhancement or maintenance of ecosystem services requires a priority setting process

The 'Inventory' approach to setting research priorities (Section 6) was appropriate for a participatory research project in which local knowledge and values guided priorities and played a central role in setting the research agenda. An extension of this approach is one that enables the prioritisation of ecosystem services based on their functional relationships.

12.5.2 A hierarchical framework of interactions between services helps setting priorities

Relationships among ecosystem services can be classified into two types:

- umbrella relationships, in which a set of services depends on the same physical conditions and processes, so that providing the conditions needed for one service at least partially satisfies the needs of other services in the relationship; and
- prerequisite relationships, in which one service produces an output or provides the conditions on which another service depends.

Ecosystem services in these relationships are either controlling or dependent. Categorisation of relationships in this way provides the basis for a prioritisation framework. The first step in implementing it is to classify services according to the scheme in Table 12.1. How the scheme works is best illustrated by example.

Example 1: under the "umbrella" category of relationships, "maintenance and regeneration of habitat" is one of the services controlling interactions among services. Getting in place the biophysical processes and conditions that are required for this service (i.e. landscape connectivity and vegetation community structure) also provides for pollination, provision of shade and shelter and maintenance of genetic resources.

Example 2: under the "pre-requisite" category of relationships, "maintenance of soil health" is listed as controlling because it provides the soil conditions and subsequently vegetation that are pre-requisite services for filtration and erosion control.

The second step in implementing the framework is to identify services that are common across relationships (Table 12.2). In this instance, "maintenance of soil health" and "maintenance and regeneration of habitat", because of the underpinning biophysical processes, have a controlling influence in both pre-requisite and umbrella relationships with other services. This suggests they should be targeted for allocation of resources when seeking to rehabilitate ecosystems services. Enhancing the biophysical requirements of these services would provide the conditions required as input to other services and coincidently enhance the provision of other services. It is notable that "maintenance of soil health" was targeted as the highest priority service in the Natural Assets Report (Binning and others, 2001). "Maintenance of genetic resources" is of next greatest importance as it is a pre-requisite for other services. "Filtration and erosion control" should be the next highest priority.

We do not propose the tables and organisation of services listed here to be definitive for all catchments. Their selection and order will depend on the definitions of services created during the Inventory process.

These tables also guide the adoption of theoretical frameworks and indicators in developing catchment management. In this instance, theories about soil processes, sediment and nutrient transportation and conservation biology will provide important understanding. Following from this, monitoring tools such as "landscape function analysis" (Tongway and Hindley 2000) and "habitat hectares" (Parkes and others 2003) should provide efficient mechanisms for monitoring progress in enhancement of ecosystem services.

Table 12.1 Identifying ecosystem service relationships using a nested hierarchical framework

	Ecosystem service relationships	
	Services included within umbrella relationships	Services included in prerequisite relationships
Services that control these relationships	e.g. 1. maintenance and regeneration of habitat;	e.g. 2 maintenance of soil health;
	(other examples: maintenance of soil health; filtration and erosion control)	(other examples: maintenance of genetic resources; maintenance and regeneration of habitat)
Services that are dependant on these relationships	e.g. 1. pollination, provision of shade and shelter, and maintenance of genetic resources require at least some of the conditions needed for maintenance and regeneration of habitat	e.g. 2 filtration and erosion control depends on the conditions that maintenance of soil health provides;
	(other examples: healthy waterways; pest control; regulation of river flows and ground water levels; waste absorption and breakdown; regulation of climate)	(other examples: regulation of climate; pollination)

Table 12.2 Identifying ecosystem service priorities using a nested hierarchical framework

	Umbrella and controlling	Umbrella and dependant
Pre-requisite and controlling	maintenance of soil health; maintenance and regeneration of habitat	maintenance of genetic resources
Pre-requisite and dependant	filtration and erosion control	regulation of climate; healthy waterways; pest control; regulation of river flows and ground water levels; waste absorption and breakdown; life-fulfilling services; filtration and erosion control; provision of shade and shelter; pollination

12.5.3 Scenarios enabled structured comparisons of options

To explore potential changes in ecosystem services in a structured way, we established scenarios in consultation with stakeholders. With the exception of the dairy enterprise, in each case study one scenario reflected current conditions as a baseline to compare with other scenarios. The other scenarios were chosen to represent desirable or undesirable alternatives, or alternatives reflecting different stakeholder groups or policies. The output of ecosystem services was then evaluated by comparing scenarios. We adapted this general approach to suit the context of each case study, but in each case stakeholder's participation ensured our scenarios were related to the priorities of managers, the Catchment Management Authority or state policy. In the dairy case study, stakeholders focused our work upon industry concerns of water use efficiency and water quality, pasture management and animal nutrition. In the floodplain case study the issue was matching land use and management options to the different land types, and vegetation response to land management was a key concern. In contrast, in the dryland sub-catchment case study the emphasis was upon state conservation policy and its consequences. The recreation and tourism scenarios were structured to explore policy alternatives at regional scale. In the input-output analysis of the Goulburn Broken Catchment stakeholders representing industrial, state and local government and CMA interests were able to guide our exploration towards the effects of structural change in the regional economy upon water use and nutrient outputs.

Interactions among variables in our case studies meant that responses of services to changes in land use or management were often unpredictable. The scenario approach enabled us to explore uncertainties as well as beneficial and unwanted thresholds. In the dryland catchment case study, for example, the response of the habitat configuration score to increasing levels of re-vegetation showed unpredicted non-linear changes and associated thresholds near the current level of native vegetation cover, and another between 30 and 40%. These have major implications for policy and implementation, which the scenario approach enables us to explore.

12.5.4 Better production functions are needed to evaluate the benefits and costs of changes in ecosystem services

We adapted a variety of approaches to build production functions for the case studies. Evaluation of the dairy and floodplain case studies were based on dynamic simulation models with integrated evaluation of ecosystem service outputs. Dynamic models can explore easily the effects of small changes in management and land use, and interactions among services can be captured well, but the capacity to explore spatial relationships is limited. Spatial capability was strong in the dryland sub-catchment case study, but the wide range of services evaluated led us to rely on a set of separate analytical techniques and models for evaluating the services separately. Given this lack of integration, interactions among services could not be evaluated comprehensively. Evaluation in the recreation and tourism case study was by expert knowledge. The ability to estimate changes in ecosystem services over time and space, and interactions among services, depends on the knowledge and human limitations of the experts. Evaluation in the input–output analysis of the Goulburn Broken Catchment was limited to water inputs and nutrient outputs by the simplicity of the model, but water and nutrients were well integrated with the structure and outputs of the economy.

In Section 4 we specified the characteristics of an ideal production function. Among the ideals are dynamic spatial behaviour, but to make ecosystem service applications available to a wide range of users we used desktop computers, which are limited by their processing capacity. Especially in the floodplain modelling (Section 8) we showed how time and space could be modelled effectively on a desktop computer by analysing a complex landscape and classifying it into a sufficiently small number of units that are relatively homogeneous within categories.

Also among the ideals is the need to address thresholds and non-linear changes in bio-physical processes, and the capacity to estimate the effects of production on the sustainability of ecosystem services. These are the subjects addressed by resilience theory (Gunderson and Holling 2001) and the international Resilience Alliance (http://www.resalliance.org/ev.php). This project is linked to the Resilience Alliance because the Goulburn Broken is a Resilience Alliance case study (Anderies and others 2002). The Goulburn Broken is also a case study in a CSIRO-funded project on the resilience of evolving social-ecological systems.

12.5.6 Requirements of ecological-economic production functions

In Section 4 we wrote of the need for production functions that provide the fundamental link between ecology and economics, a link that would support a new discipline of ecological economics (Mayumi and others 1998). Our case studies are a contribution in this quest. Table 12.3 shows the scientific and performance criteria that need to be satisfied, with comments on the contributions of our case studies. We do not imply that it will necessarily be worthwhile to build comprehensive production functions satisfying all these criteria within the one model. In most cases a set of partial analyses may be more cost-effective. The choice of models and analytical methods should be driven by the purpose and context of the analysis, more detail is not always better, and much useful work can be done with simple models.

12.5.7 Combining citizen's jury and multi-criteria evaluation is a powerful way to capture and develop community values

The Deliberative Multi-criteria Evaluation developed in this study provided a powerful means by which stakeholder values can be captured and complex decision problems broken down into more manageable pieces. The Citizens' Jury process enabled several decision-makers to express their priorities, debate their positions and learn more about the decision problem by calling on expert knowledge. The Jury process combined well with Multi-criteria Evaluation, which allowed for the unravelling of complex decision problems and the identification of trade-offs. The development of an impact matrix through expert input meant that decisions could be made regardless of the availability of formal information. The process showed the importance of asking the right questions, particularly about ecosystem services. It also brought out the central importance of ecosystem services in decisions about land use and natural resource management.

12.5.8 Complex research projects are likely to miss deadlines

The extensive gaps we found in theory, methods and data coupled with the complexity of the interactions in the systems we studied meant that some delays were experienced in producing the analyses expected by our stakeholders. The breadth of our analyses made us dependent on data generated by models that other researchers were developing, and as their timelines slipped, so did ours. For example, in the floodplain study (Section 8), we depended on flood extent and duration data from the model developed by sub-contractors to the consultants who were in turn contracted to the Goulburn Broken Catchment

Management Authority. These groups cooperated fully in our research. However, the extreme complexity of their model, its sensitivity to minor errors in the precise digital terrain model upon which it was built, and the changing information requirements of the CMA led understandably to delays that have not yet ended. Lacking input data, our floodplain model is still not operational, and is a demonstration of a concept, not proof of it.

Another example was our work in the dryland sub-catchment (Section 9). For the analyses of the hydrological consequences of vegetating the dryland sub-catchment, we depended on a model being developed for another project in the catchment. When it became apparent that this was not going to be ready on time, one of our researchers learned how to model point estimates of evapo-transpiration, drainage and run-off, while a colleague at CSIRO Land and Water built the spatial hydrological framework to integrate the point estimates.

Such delays are to be expected in research, which by definition is exploring areas of ignorance. However, this problem is exacerbated in ecosystem services research where analysis of multiple services is necessary, so our dependence on external expertise is increased, with a commensurate increase in the likelihood of delay. We have managed this risk by building both internal capacity, and a network of external collaborators.

Some key data have still not arrived as we go to press, so that to do justice to the research we may need to return to the analyses after the formal end of the project. Again, this problem is common to most research projects, but the breadth of the range of services studied multiplies the likelihood of data delays, and increases the vulnerability of models to missing data.

12.5.9 Impediments to data sharing provide a significant barrier to understanding complex social-ecological systems

All our case studies suffered delays because of difficulties in obtaining data, with Government managed data particularly slow to obtain. One impediment is the absence of a standard data license agreement accepted by Federal and State Governments. Presently, data licenses are created by individual organisations and vary in restrictions on data use and ownership of data generated by the user. Variation of these licenses requires time-consuming consideration by the legal departments of the individual organisations. A common Government data license would be more efficient. Another impediment is the move of many Federal and State organisations to claim intellectual property in data sets created by their publicly funded organisation. The cost of accessing data impedes research and when transfer is between departments there is no gross gain to public funds whereas there is significant net loss due to administrative overhead.

Table 12.3 The contribution of our case studies towards ecological-economics production functions

	Dairy	Floodplain	Dryland sub-catchment	Tourism and recreation	Economy, water and nutrients
Calibration of models and analyses against empirical data	Functional relationships from literature and expert knowledge, with explicit assumptions when these are unknown.	Functional relationships from literature and expert knowledge, with explicit assumptions when these are unknown.	Functional relationships from literature and expert knowledge, with explicit assumptions when these are unknown.	Functional relationships from expert knowledge.	Linear functional relationships imposed on empirical data by the input-output model.
Validation of models and analyses against independent empirical data or expert knowledge	Expert knowledge.	Field checks of predicted native vegetation patterns. Long term predictions of vegetation patterns and structures impossible to validate now. Has passed 'laugh tests' with local experts. Filtration module cannot be validated without substantial field research.	Only stream flow was validated against the hydrograph. Other outputs were not validated because they occur in the future or were too costly to measure.	Expert knowledge.	Expert knowledge.
Dealing with time	Used a human economic planning timescale of 20 years in annual time-steps. Appropriate for decisions made now about investments affecting sustainability.	Annual time-steps with a time horizon of 100 years or more if required. Succession from cleared paddock back to a pre-European vegetation structure likely to take centuries.	A mixture of approaches. The succession of native vegetation takes centuries. We treated all native re-vegetation as if it was 'climax' because the modelling of multiple successional stages and their transitions was too complex. Hydrological processes were run over the period 1980-2000.	A timeframe of 20 -50 years was assumed for the various scenarios to allow for differing points of time when the full impacts of some of the assumptions would be felt. This was also necessary to be consistent with inputs from other studies used.	Snapshot only — no time steps.

	Dairy	Floodplain	Dryland sub catchment	Tourism and recreation	Economy, water and nutrients
Dealing with space	Non-spatial. This limits the capacity to model off-site effects of nutrient emissions.	The complexity of the floodplain was reduced to around 300 mapping units, each reasonably uniform in soils, vegetation and flood regime.	This was our highest resolution analysis (one ha) because we needed to represent vegetation types as pure units for evaluation purposes. It would not have been feasible to run this analysis in an integrated dynamic model at this level of spatial resolution.	Regional -impacts were confined to the upper catchment.	Non-spatial.
Incorporation of industrial and ecosystem inputs?	Industrial inputs incorporated. The weakness was lack of knowledge of ecosystem services.	Standard applications of agri-chemicals assumed. Focus mainly on ecosystem services. Interactions of industrial and ecosystem inputs not modelled.	No commercial production in the runs reported here. Standard applications of agri-chemicals is assumed for future runs.	For some scenarios both human-made and ecosystem services inputs were assumed.	Industrial inputs represented in terms of their dollar costs. Water was the ecosystem service input.
Estimation of impact of current production on future production?	Feedback loops from production to ecosystem function and back into production not completed, mainly due to lack of knowledge.	Some feedbacks built in. Livestock browsing on native vegetation slows regrowth, and native vegetation younger than 10 years old can be cleared for cropping.	The shade and shelter, erosion hazard and soil acidification outputs imply positive and negative effects on future production, but no formal feedback loops included.	No feedback loops explicitly incorporated.	N and P outputs imply a decline in water quality, but no formal feedback loops included.
Estimation of externalities	N, P, and carbon storage estimated.	Carbon storage and filtration capacities estimated.	Carbon storage, P, sediment load in stream and stream water yield.	Quantitative estimates of stream water yield plus an Index of Stream Condition.	N and P outputs are externalities.
Ability to represent non-linearity	No thresholds modelled.	Vegetation states and transitions recognised in the method, but in the model change is incremental.	Non-linear change handled through reconfiguration of analysis to suit scenarios.	Not incorporated.	Non-linear change handled through reconfiguration of analysis to suit scenarios.

12.6 OBJECTIVE: Recommend policies and practices that maintain ecosystem service values

12.6.1 Investment to increase understanding of biophysical processes is a necessary foundation for better management of ecosystem services

Many policy makers and funders believe that most degradational processes are scientifically well understood, and that implementation should proceed without further investment in research. However, the development of incentive or regulatory schemes, or markets for ecosystem services, even at a pilot level, needs reliable estimates of responses of ecosystem services to changes in vegetation cover or management. Participants, including governments, cannot be expected to commit resources when uncertainty is high. Schemes that proceed and fail through lack of biophysical understanding will discredit approaches that would have worked if knowledge had been sufficient. In our research we found large gaps in knowledge about:

- natural pest control on dairy pastures by birds and other predators;
- the role of soil fauna and flora in decomposition of cattle dung and the maintenance of soil fertility, and the impacts of pasture management on those flora and fauna;
- water filtration by floodplain vegetation;
- the regeneration, growth and structural changes of native vegetation over time, and associated changes in species composition and 'Habitat Hectares' score;
- the sources of in-stream salinity — one view was that it is mainly from run-off, another held that the prime source is ground-water;
- the impacts of recreation and tourism on ecosystem services; and
- water consumption and nutrient emissions from sectors of the catchment economy.

These gaps in knowledge often left us unable to calibrate, and validate models and analyses and in many cases meant that our researchers had to evaluate ecosystem services without well-established knowledge and data. Where stakeholders identified a priority ecosystem service that is produced by ecosystem processes that are poorly understood, there is a strong case for investing in basic research. The many knowledge gaps we identified show there is a lot of that to be done. While the priorities will be different in other Australian catchments, the social and environmental returns to investment in research could be high if prioritisation followed the inventory and functional approaches we developed. (Binning and others, 2001; This report — sections 6 and 12.5.2)

12.6.2 New incentives, regulations or markets are needed to protect ecosystem services that are over-exploited or under-managed

For policy purposes, a priority setting approach based on property rights encourages a focus upon ecosystem services that are vulnerable because of the tendency of humans to under-manage or over-exploit them. The majority of ecosystem services that are susceptible to degradation are those that have not been captured by private or common property (group) rights, so that benefits and responsibilities are not attributed to an individual or group (Ostrom 1990). They are difficult to assign, or are considered by individuals to be not worth capturing because:

- the physical or temporal boundaries of the processes generating the service are not easily defined, e.g. perennial vegetation at one place controlling the rise of saline water tables elsewhere; storage of carbon in vegetation to regulate future climatic change. Private management of such services is difficult because of their dispersed nature, it is difficulty to excluding use by others, and collective solutions carry high transaction costs;
- they are not yet scarce, (e.g. the filtration capacity of native vegetation) even though their value may be high; and
- their value may be low.

The consequence is that relatively cohesive groups of users organise themselves around ecosystem services that are scarce and have clear biophysical boundaries. The benefits are therefore marketable and would-be users lobby for property rights. They subsequently lobby effectively for policies that favour their way of using the resource. An example is the agricultural lobby (Godden 1997). On the other hand, benefits from services without clear biophysical boundaries, or with boundaries that do not match farm, forestry or conservation area boundaries, are likely to have weak or no property rights (open access). They are therefore less likely to be marketable, and so incomes are less likely to depend directly on such services. Groups valuing these kinds of ecosystem services are generally more diffuse, less well-resourced and less powerful (Scheffer and others 2000). The lack of property rights and low level of political support makes degradation of these services likely, and sustainable solutions difficult because of high transaction costs arising from lack of social cohesion and diffuse bio-physical boundaries.

These open access services are the ones where new institutional arrangements may promote sustainable use. These could be based on some combination of new property rights, regulations, incentives and markets. An example is the provision of clean water from agricultural sub-catchments. This service is dispersed across the properties in the catchments, and agreements among farmers would be needed in order to realise the benefits of managing the whole catchment to improve water quality. Water users could make payments for the provision of the service. Used in combination with the framework illustrated in Table 12.2, a property rights approach can focus policy and research effort on services that are both functionally important and vulnerable.

12.6.3 The tourism and recreation case study identified particular policy needs for maintaining ecosystem services that support that sector

Through the workshop process the case study highlighted the need for greater research on public access issues, the effects of education on tourists and environmental damage, methods for the recovery of management costs and the role of market and other incentives in limiting environmental damage of recreation and tourism activities.

12.6.4 The sub-catchment case study shows where investment in native vegetation is worthwhile

The conservation rules for vegetation enhancement in the Sheep Pen Creek case study are drawn from State policy. Investment priorities can be set for any future time period if the input data are updated to reflect past on-ground plantings inside or outside the sub-catchment. Running the GIS-based models to achieve an incremental increase in the target identifies the next set of sites for priority planting. The rules and their weightings can be changed as new information is acquired from the sub-catchment or outside. The approach could also be applied at a broader scale, perhaps with different rules and weightings in different zones.

12.6.5 A native vegetation target of 15% produces only small increases in ecosystem services

Modelling of revegetation in Sheep Pen Creek suggests that an increase from the current level of 8% of native vegetation to a 15% target produces only small gross increases in ecosystem services (Habitat Configuration Score, carbon storage, shelter, shade, stream sediment load, sheet and rill erosion control, deep drainage control and control of soil acidity.

12.6.6 The response of ecosystem services to landscape changes may have thresholds that indicate where efficient revegetation targets should be set

Our analysis of Sheep Pen Creek shows a non-linear relationship between area under native vegetation and Habitat Configuration Score. The score per hectare increases rapidly as the cover of native vegetation increases from the current level to a cover of 10%. This is probably because the current pattern of remnants was determined by agricultural, not nature conservation decisions. The revegetation is driven by conservation rules, and rapid gains per vegetated hectare in Habitat Configuration Score are made as the many conservation opportunities are taken up. As cover increases above 10%, these opportunities decrease, and the gain in score per vegetated hectare declines until about 33%, after which it increases again. The thresholds revealed by this work can guide cost-effective investment in revegetation for restoring habitats — a target of between 30 and 40% gives a good Habitat Hectares Score per hectare.

12.6.7 Policies aimed at restructuring the regional economy could increase the efficiency of water use without necessarily reducing jobs or gross regional product

The input-output analysis of the economy, water use and nutrient outputs illustrates which sectors could be targeted by regional development policies in order to restructure the economy to achieve more efficient use of water in the generation of dollar outputs or jobs. It can also examine, within the limitations of the data, changes in the relative levels of economic activity of the sectors to reduce total pollution. The constrained optimisation approach we developed is an effective way of engaging industry groups and state policy makers in exploring the possibilities of alternative economic configurations and ways of achieving them.

12.6.8 Increased understanding of ecosystem function at different scales can improve the cost-effectiveness of investments in natural capital

In the past, vegetation patterns in catchments have been determined by property-scale decisions of farmers. The resulting vegetation patterns are inefficient for regulating salinity or conserving biodiversity, because many of the biophysical processes do not operate at property scale. To achieve efficient salinity control and biodiversity conservation, vegetation patterns and the policies that influence them need to be determined at sub-catchment scale or broader.

The Goulburn Broken Catchment is already pioneering ways of investing in natural capital, and the ecosystem services concept contributes to their strategic investment planning. From our case studies at enterprise, landscape, sub-catchment, regional and whole-of-catchment scales we can estimate the effectiveness of investment in natural capital at each scale, and consider the form of natural capital to invest in (e.g. commercial forestry or native vegetation). However, an investment in natural capital at one scale affects processes at other scales too. Obvious examples are an effluent pond on a dairy farm improves water quality downstream; afforestation in the upper Goulburn Catchment affects downstream water flows and quality, and revenues from tourism too. Our preliminary quantification of flows of ecosystem services at selected scales can contribute to a plan for strategic investment in natural capital that takes explicit account of scale effects. It enables better prioritisation of resource degradation issues, and replaces arbitrary targets for remediation, such as percentage tree cover, with process-based spatial layouts, for example the rule-driven revegetation patterns in the dryland catchment case study. The suite of models and analytical approaches we developed illustrates the strategic potential of a cross-scale approach, from the input-output model that links the economy of the catchment to water flow and quality, to the dairy model that addresses the same issues at a fine scale and from a very different perspective. The low priority given to ecosystem services by dairy farmers at the scale of the farm reinforces the importance of cross-scale analysis: we have already pointed out that the farm is dependent on water supply, purification and carbon storage services provided at a broader scale.

12.6.9 Policies and practices for maintaining or enhancing ecosystem services

A set of policies and practices to maintain or enhance ecosystem services arises from our findings. Some can be generalised, others are specific to the Goulburn Broken Catchment. They are summarised in Table 12.4, which also shows how they contribute to the sub-strategies of the Goulburn Broken Catchment Management Authority.

Table 12.4 How case study recommendations relate to the management strategies of the Goulburn Broken Catchment

Case study recommendations			Catchment Management Strategies									
Ecosystem services being enhanced: L = Life fulfilling services C = Regulation of climate H = Maintenance and regeneration of habitat P = Pest control Sh = Provision of shade and shelter F = Filtration and erosion control So = Maintenance of soil health W = Maintenance of healthy water ways G = Regulation of river flows and groundwater levels A = All of the above	Responsibility for implementation (c= CMA, s=State, f=Federal)	Ecosystem services (see legend)	Soil Health Strategy	Shepparton Irrigation Region Catchment Strategy	Floodplain Management Strategy	Dryland Salinity Management Plan	Water Quality Strategy	Riverine Health Strategy	Native Vegetation Management Strategy	Upper GoulburnCatchment Recreational Waterway Strategy	Climate Change and Greenhouse Gas Abatement	Weed & Rabbit Action Plans
Water Inputs and Nutrient Outputs from the Goulburn Broken Economy												
Develop regional development policies that take account of the sectoral output, employment, water and nutrient multipliers and promote economic restructuring.	s	W		✓			✓					
Tourism and Recreation												
Adopt deliberative processes combined with multi criteria evaluation in the development of other sub-strategies and plans for the Goulburn Broken Catchment	cs	A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Invest in research on :												
• public access	csf	A								✓		
• public education and the maintenance of ecosystem services	csf	A								✓		
• an efficient set of measures for reducing damage to or enhancing ecosystem services (e.g. user pays, markets and regulations).	csf	A								✓		
• the utility of a code of practice for operators for reducing damage to ecosystem services.	csf	A								✓		
• the scope for reducing the number of or coordinating the many agencies involved in managing ecosystem services in the upper Goulburn Catchment.	csf	A								✓		
Re-vegetation of a Sub-catchment												

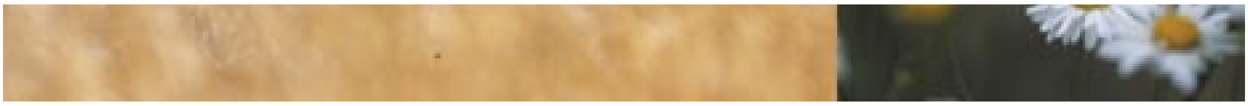
Increase native re-vegetation targets to take advantage of thresholds in ecosystem service responses e.g. above 30% of the area re-vegetated for Habitat Configuration score, and around 40% for shelter.	c	H							✓			
Given these thresholds, investments should be focused, not spread across the Goulburn Broken Catchment.	c	H							✓			
Link incentives for re-vegetation to sub-catchment plans so that efficient trade-offs are made among the ecosystem services 'maintenance and regeneration of habitat', 'provision of shade and shelter', 'water filtration and erosion control', 'maintaining healthy waterways', and 'regulation of groundwater and river flows'. These services are more-or-less sensitive to the spatial arrangements of the vegetation.	c	H Sh F W G	✓			✓	✓	✓	✓			
Design incentives for native re-vegetation so they promote re-planting of species appropriate to the Ecological Vegetation Class (EVC) in which each site lies, on sites:												
• that are geographically dispersed in order to reduce risks	c	H							✓			
• in areas where where the soils are locally variable – this increases the range of habitat possibilities in a given area.	c	H							✓			
• in EVCs that are rare in the bioregion, so that representation of these EVCs is increased.	cs	H							✓			
• where rare and threatened species occur in order to enhance their survival	cs	H							✓			
• near existing remnants that have a higher canopy density. This builds connections among remnants in which the higher canopy density indicates better habitat for native biota.	c	H							✓			
• in areas where patches of remnant vegetation are already numerous. The habitat value of the planted site is enhanced by the adjacency of the remnants.	c	H							✓			
• near larger existing remnants. The habitat value of the planted site is enhanced by the size of the remnant.	c	H							✓			
• near streams as these provide good habitat for native fauna and several other ecosystem services.	c	HWF							✓			
• that are enclosed by native vegetation. This enables small remnants to coalesce into a large patch with a higher overall habitat value.	c	H					✓	✓	✓			
• that make short links between remnants as fauna using short corridors may be less vulnerable to predation.	c	H							✓			
• far from productive agricultural land to reduce the risks from intensive management practices.	c	H				✓			✓			
Invest in an adaptive management research program on regeneration of native vegetation, the evolution of Habitat Hectares scores, and the interventions required to achieve benchmark structures and species compositions.	cs	H							✓			

continued next page

Table 12.4 continued. How case study recommendations relate to the management strategies of the Goulburn Broken Catchment

Case study recommendations			Catchment Management Strategies									
Ecosystem services being enhanced: L = Life fulfilling services C = Regulation of climate H = Maintenance and regeneration of habitat P = Pest control Sh = Provision of shade and shelter F = Filtration and erosion control So = Maintenance of soil health W = Maintenance of healthy water ways G = Regulation of river flows and groundwater levels A = All of the above	Responsibility for implementation (c= CMA, s=State, f=Federal)	Ecosystem services (see legend)	Soil Health Strategy	Shepparton Irrigation Region Catchment Strategy	Floodplain Management Strategy	Dryland Salinity Management Plan	Water Quality Strategy	Riverine Health Strategy	Native Vegetation Management Strategy	Upper GoulburnCatchment Recreational Waterway Strategy	Climate Change and Greenhouse Gas Abatement	Weed & Rabbit Action Plans
Floodplain												
Develop recommendations for floodplain policies and practices.	c	HGWFC			✓		✓	✓	✓		✓	✓
Invest in an adaptive management research program on regeneration of native vegetation under different flood regimes, the evolution of Habitat Hectares scores, and the interventions required to achieve benchmark structure and species composition.	cs	H			✓				✓			✓
Invest in research on the filtration of water by floodplain vegetation.	cs	FW			✓		✓	✓	✓			
Dairy enterprise												
Strengthen policies (e.g. water markets, water property rights, water quality monitoring and regulation, tradable pollution permits) that promote water re-use and nutrient retention on farm.	sf	WG		✓			✓	✓				
Strengthen or establish policies (e.g. offset schemes) that promote establishment of native vegetation on outblocks (or elsewhere) to compensate for greenhouse gas emissions from, and lack of habitat for native species, on the milking areas.	sf	H							✓		✓	
Invest in research on soils and soil organisms under intensive irrigation and fertiliser regimes. Are there long term trends or critical thresholds? What are the limits of intensification? Can irreversible changes occur? Is the balance of soil ecosystem services to industrial inputs financially efficient and sustainable?	s	So	✓	✓								
Invest in research on natural pest control in pastures.	s	P	✓						✓			

13 Future work



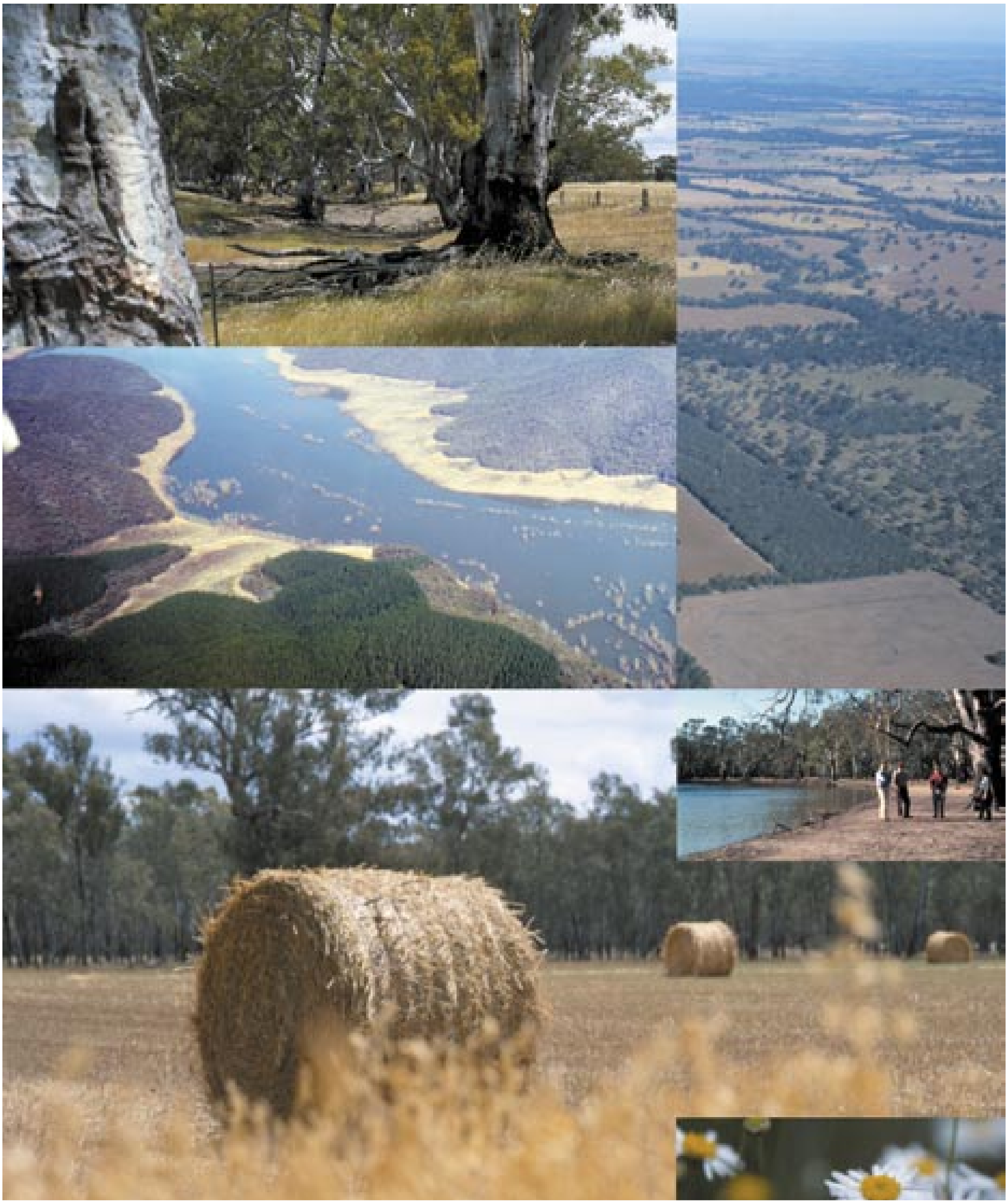
13. FUTURE WORK

Markets for ecosystem services

A high priority for future work is to analyse the institutions needed to maintain ecosystem services, and in particular explore ways of matching the scale and the design of institutions to the scale and nature of the ecosystem processes they are intended to influence. Another priority is to explore the feasibility of markets for ecosystem services, including the supporting institutions. We launched a new project in 2002, which is an attempt to redress market and property right failures and encourage investment in natural capital (http://www.ecosystemservicesproject.org/html/markets/aboutus/index.htm). It is funded by CSIRO, the Rural Industries Research and Development Corporation, Land and Water Australia, the Goulburn Broken CMA, NSW Department of Sustainable Natural Resources, Colleambally Irrigation, the Blackwood Basin Group, and the National Market Based Instruments Program. A supporting project on experimental economics funded by CSIRO will explore the decision-making behaviour of resource users under controlled conditions.

Ecosystem services linking town and country

A proposed ecosystem services project is called “Putting Ecosystems to Work for Town Water Supply”, this project would draw upon the experiences of the Ecosystem Services Project and the Markets for Ecosystem Services Project in making use of natural capital to provide clean water to towns through ecosystem services markets in rural catchments. We envisage a pilot project that is expected to lead to changes in policies affecting the provision of clean water to towns from rural catchments. We predict a spread of similar projects as the costs of providing clean water increase in Australia and globally.



14 Concluding remarks

14. Concluding Remarks

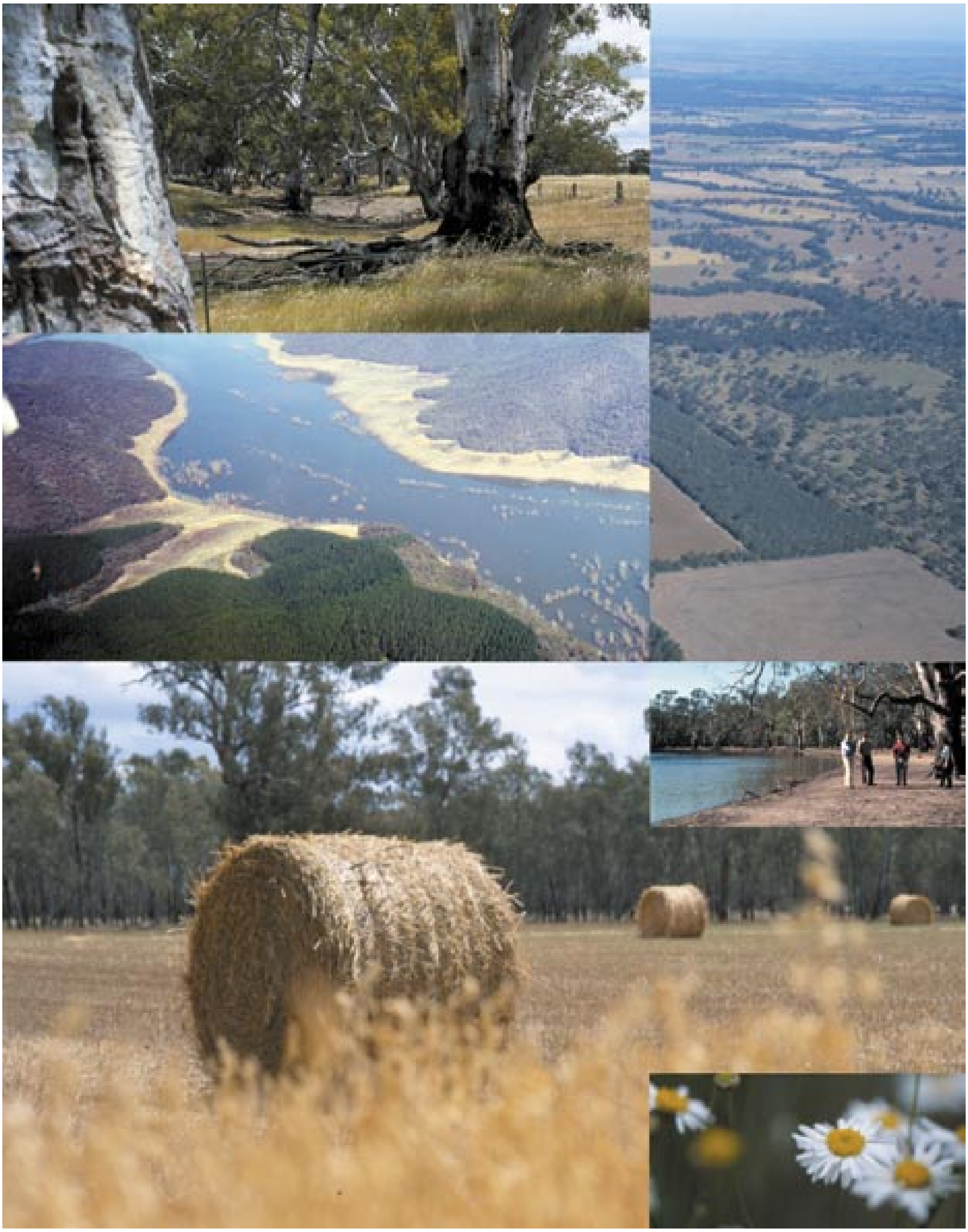
The ecosystem services concept is rapidly influencing the way stakeholders perceive the relationships between natural capital and development, and is encouraging investment in natural capital, markets for ecosystem services, and in related research and communication.

If humans perceive themselves as separate from nature it then follows that development has no environmental cost. The contradiction of historical development is that it has caused the degradation of natural capital even though human well-being and survival depend on the services provided by that capital. The ecosystem services concept places humans and their economies within ecosystems so that 'natural' and economic processes are intimately interconnected. It is a step towards the integration of ecology and economics. It shows the need for investment in the maintenance of natural capital because it is the primary source of value and the provider of life support. This idea is obvious, but the reluctance of societies to bear the costs of maintaining natural capital show the need for frequent restatement and reinforcement of the idea. The ecosystem services concept changes the need for investment in natural capital from an option to an imperative.

The Goulburn Broken Catchment Management Authority is already pioneering ways of investing in natural capital, and the ecosystem services concept contributes to this investment. In its simplest form this project's quantification of ecosystem services at selected scales (case studies) contributes directly to catchment planning. Above this, the awareness of transfer of services across scales can contribute to investment in natural capital that takes explicit account of otherwise unrecognised scale effects.

Within the framework of ecosystem services there is a range of ways to integrate ecological, economic and social values. The choice and definition of the services, an inherently social process, is critical to their understanding. They define the set of biophysical processes that underpin the ecosystem services, processes that lead to interactions between services and provide the indicators for the relative performance of each service. However, the processes are often poorly understood and greater investment to link process with service is required to ensure the ecosystem services concept reaches its full potential and utility. Analysis can vary in scale from enterprise to catchment and can utilise tools from dynamic modelling to multi-criteria evaluation. All should be linked with participatory methods that connect researchers and community together. This increase in understanding of ecosystem processes is fundamental to the establishment of markets for ecosystem services, and for political acceptance of the need for other changes in institutions for natural resource management.

To take the concept of ecosystem services further it is imperative to build on three themes introduced in this project. Firstly, production functions that recognise spatial, temporal and feedback components of ecosystem services will provide the necessary link between ecology and economy by providing a mechanism by which disparate values can be evaluated in like terms. Secondly, it is unlikely there will be sufficient investment in environmental management to match the extent of degradation. There is therefore a strong need for priority setting tools that can guide society's investment in the management of ecosystem services. The nested hierarchy framework presented in this report is one process for setting priorities. Lastly because many ecosystem services are not readily captured and managed within private property rights institutions, there is a need for new institutions that will protect the value of these services.



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