Land use in catchments: exploring new patterns for fairness and efficiency

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Abstract
Can the pattern of land use in a catchment be changed so that the net benefits to society are increased? If so, how would changing to the new pattern of land use affect the distribution of benefits and costs among stakeholders? Tools for answering these questions must be able to model biophysical processes in time and space, link these models to farm and regional economic models, include a wide range of stakeholder values and the land uses by which they are realised, provide a participatory process that addresses conflicts and encourage participants to find new opportunities and win-win solutions, and support the process with transparent, user-friendly interactive software. No one tool can meet all these criteria. In this paper we discuss the application of a participative process and LUPIS$^+$ software in a 'proof of concept' case study, and in the exploration of the values of ecosystems services in two subcatchments in Victoria and New South Wales. While it is too early to report conclusions, we can report that we have learned much about social and ecological dynamics, and recognise the need to explore transitions towards a better pattern of land use, a capability that is built into the process and the software.

Keywords
biophysical processes, catchments, community participation, ecosystem services, efficiency, equity, land use

Efficiency and equity of land use in catchments
Agricultural production is the dominant land use in many Australian catchments. It yields revenues and life-style benefits, but it carries costs. Some of these, such as land degradation, are borne directly by the farmers or their successors. Other costs are externalities — costs that are borne by society. Rising water tables and salinisation, pollution of streams through erosion and agricultural chemicals, and declines in native species are examples. Recognising these problems, governments have made catchments the focus of policies and plans to address the problem of agricultural externalities. The policy questions to be resolved are:

- Could a different pattern of land use in a catchment deliver a higher net benefit to society? In other words, is the current pattern of use economically inefficient? (Efficiency can be defined at the scale of the catchment, the region, or more broadly.)
- If so, how would changing to the new pattern of land use affect the distribution of benefits and costs among farmers? In other words, what system of cost-sharing would be needed to encourage voluntary change towards the socially desirable land use pattern?

In using the concepts of efficiency and equity, we are taking an economic view of catchments. This does not mean that benefits and costs are necessarily measured in monetary terms, nor that they need to have direct or indirect use values to people. Intrinsic values (values of things that may have no use value, such as some rare species) are included in the benefits to society (Pearce and Turner 1990).

The two questions above are clear, but answering them is not straightforward, for reasons that include the following:

- Some of the benefits and costs to society, even when they can be expressed in monetary terms, are difficult to estimate because they depend on biophysical processes that are not easy to predict in time and space because the processes are intrinsically unpredictable or we do not have knowledge of the processes (e.g. the effect of clearing native vegetation on the pollination of commercial crops). That management actions are often separated in time and space from their consequences compounds the difficulty.
- Other benefits might not be valued in monetary terms; for example, some landholders value a farming way of life for its own sake, and conservationists value native species for their intrinsic values rather than their use values.
- Benefits and costs change over time because of changes in biophysical and social systems, and consequent shifts in supply, demand and value. They also change as new knowledge changes perceptions of value.
- Benefits and costs depend on the context. Spatial context is an obvious example: head-of-catchment farmers may benefit little from planting trees that bring large benefits to farmers further down the catchment. Another example is spatial patterns of vegetation (size and shape of patches, connectivity) that have a strong influence on the quality of habitat for a variety of species. Temporal and social contexts matter too: native vegetation has had low or negative values to society in the past. It is now valued highly by some stakeholders.

The purpose of this paper is to discuss the application of a participative process and LUPIS$^+$ software in a ‘proof of concept’ case study, and in the exploration of the values of ecosystems services in two subcatchments in Victoria and New South Wales. We illustrate the method by describing the biodiversity component of our work, emphasising that other components will receive equivalent effort. While it is too early to report conclusions, we can report that we have learned much about social and ecological dynamics, and recognise the need to explore transitions towards a better pattern of land use, a capability that is built into the process and the software.

Tools for exploring land use change

There is a strong and growing need to appraise new land use options for catchments. Criteria for designing or selecting an ideal appraisal tool or toolset include the ability to do the following:

- *model key biophysical processes in time and space* — spatial heterogeneity and temporal variability make the estimation of net benefit streams a difficult task
- *link these models to farm and regional economic models* — so that private and social benefits and costs can be estimated and compared
- *include a wide range of stakeholder values and the land uses by which they are realised* — so that equity is potentially achievable
- *provide a participatory process* that addresses conflicts and encourages participants to discover and learn about new opportunities and win–win solutions
- *support the process with transparent, user-friendly interactive software* so that participants are not alienated by the process.

We are nowhere near being able to satisfy all these criteria with a single approach, but the Victorian and New South Wales governments, the Australian Bureau of Agricultural and Resource Economics and CSIRO’s Divisions of Land and Water and Sustainable Ecosystems, among others, are developing processes and models. We are optimistic that a useful toolset will develop out of this diversity. This paper is about one approach being tested by CSIRO. It is a relatively transparent, participative approach, designed to include the knowledge and values of farmers and other stakeholders, Catchment Management Authorities, boards and agencies, as well as scientists. It uses a mediation process supported by LUPIS$^+$ software (Ive and Cocks 1999, CSIRO 2001).

A value-driven participatory approach

LUPIS$^+$ produces maps of alternative land use patterns. Land allocation is driven by guidelines written by participants, who also allocate votes that influence the relative importance of each guideline. The process can be followed without the software, or by using alternative software such as a geographical information system and a multicriteria package, but LUPIS$^+$ has capabilities that are not available in other software. It is designed for exploring options and examining trade-offs in a quest for a pattern of land use that satisfies multiple goals efficiently; that is, with the lowest cost in terms of opportunities forgone.

The Heartlands and Ecosystem Services projects (see www.clw.csiro.au/heartlands/ and www.ecosystemservicesproject.org for more information) are applying the method in two areas of Victoria and New South Wales. LUPIS$^+$ is being used in the ecosystem services project to compare the ability of alternative land use patterns to yield ecosystem services: control of water tables, carbon storage, habitat for native species, maintenance of landscape function, and provision of fodder, shade and shelter.

The purpose of the Heartlands application is a 'proof of concept'. Participants will be individuals selected from the farming community and state government agencies. This process will provide knowledge on which to base a later exercise in which the community and agencies are properly represented. At no stage is the intention to produce a land use plan for implementation. The maps and supporting information generated in the process are intended to show priority areas for land use change. We envisage that land use changes will occur through equitable systems of incentives and regulations, and that approaches like ours will contribute to their design.

The process and the software

The process for exploring land use change is participatory, and the outcome depends on the values of the participants. LUPIS$^+$ is therefore designed to be relatively transparent, and to be operated interactively with participants. It is also designed so that participants with different values learn about each others' perspectives. The steps are described below.

Setting spatial boundaries. LUPIS$^+$ can run at any scale, from paddock to nation. The Heartlands and Ecosystem Services projects are working in one subcatchment within the Goulburn–Broken catchment in Victoria, and one within the Billabong Creek catchment in New South Wales.

Identification of participants. This step is critical to the direction that the process subsequently follows, because the process is driven by their values and influenced by their knowledge. The quest for improved efficiency and equity of land use will not be met if a group with an interest in the catchment is excluded. An advantage of the LUPIS$^+$ approach is that it enables participants to explore value conflicts and seek win–win solutions. In the Victorian and the New South Wales subcatchments, stakeholders include conservationists, farmers and water managers.

Identification of land use issues. LUPIS$^+$ can only address spatial issues. Non-spatial issues provide background to the process. Spatial issues are prioritised and incorporated into subsequent analyses. Again, the scope of the issues will be determined by the range of participants. Issues in the Victorian and the New South Wales subcatchments include farm profitability, salinity, land degradation, water quality and biodiversity status.

Identification of candidate land uses. A candidate land use is any land use that participants deem to be a potential use. The range will also depend on who the participants are. In the Victorian and the New South Wales subcatchments, uses include grazing, cropping, agroforestry, plantation forestry, nature conservation on public land, and nature conservation on private land.

LUPIS$^+$ is able to incorporate multiple land uses in a structure that recognises a preferred use, as well as permitted, conditional and proscribed uses, on each mapping unit. This enables us to group an agricultural land use together with a biodiversity conservation land use with which it is compatible, so that the two are allocated together. The capacity for multiple land use allows the identification of opportunities to realise multiple goals, thus increasing efficiency or equity. The structure also recognises that land uses can be described in various levels of detail; for example, grazing may be divided into sheep and cattle grazing, and sheep grazing into breeding and dry sheep operations. In principle there is no limit to the number of levels that may be included in the hierarchy. The different levels of land use capture the diversity of interest and understanding that participants express in formulating guidelines that may be directed at any specific level; for example, agencies may direct guideline attention to the highest level (e.g. grazing), peak bodies may formulate guidelines at industry levels (e.g. sheep or cattle), and individual graziers at the activity level (e.g. breeding or dry sheep operations).

Construction by participants of guidelines for allocating land uses to mapping units. Guidelines should seek to capture recommended or futuristic practices, rather than past practices that have contributed to current problems. Guidelines can be expressed in three ways (Table 1). Exclusion guidelines prevent a particular land use being allocated to mapping units with specified attributes (e.g. exclude piggeries from units upwind of towns). Commitment guidelines allocate a particular land use to all units with specified attributes (e.g. commit all units with more than 30% native vegetation cover to biodiversity reserves). Preference guidelines are about the relative suitability of mapping units for particular land uses.

We advocate the use of preference guidelines rather than the other categories because land uses will tend to be allocated to mapping units to which they are best suited, and the pattern of land use that emerges will be more efficient than one where territorial claims are staked. In section 5.1 we discuss the origin of guidelines for the biodiversity component of the process.

Table 1 Examples of guidelines.

Exclusion guidelines	**Rationale and limitations**
Exclude irrigated agriculture from all mapping units with rapid rates of deep drainage	Addresses the problem of rising saline watertables, but leaves no room for technological solutions.
Exclude on-farm conservation from all mapping units with fertile soils.	Reflects the historical pattern of land allocation, but does not acknowledge the important contribution of fertile soils to a set of sites representing the diversity of a bioregion.
Commitment guidelines	
Commit irrigated agriculture to all mapping units near surface water sources.	Reflects the historical pattern of land allocation, but narrows the options by preventing the achievement of non-production goals.
Commit all mapping units with high soil fertility to intensive cropping.	Reflects the historical pattern of land allocation, but narrows the options by preventing the achievement of non-production goals.
Preference guidelines	
As far as possible, allocate irrigated agriculture to mapping units where conservation value is low.	Preference guidelines are written as sets that collectively promote the allocation of a land use to more suitable units. Through competition with other land uses and other guidelines, an efficient allocation is produced.
As far as possible, allocate mapping units with fertile soils to on-farm nature conservation.	Again, this is one guideline in a set that together seek the allocation of land to a representative bioregional reserve system. By addressing what is important for a regional conservation strategy and not excluding or committing land uses, the opportunity cost of conservation is reduced.

Data and supporting models. Each land use requires a particular set of land attributes to support it. Attributes can include bio-physical properties such as soil moisture storage capacity of soils, structure or species composition of native vegetation, as well as aesthetic attributes such as scenic value, and economic ones such as nearness to labour sources. The guidelines tell us what data to collect, so ensuring that the process is driven by values, not data nor preconceptions. This approach avoids the collection of unnecessary or inappropriate data. Most data are supplied by the Department of Natural Resources and Environment and the Department of Land and Water Conservation from previous surveys and research. Some data are generated by models developed by the Heartlands, Ecosystem Services and other current projects (e.g. groundwater flows and salinisation hazards). Some will come from participants, some is from scientific publications. Our approach is to use the best data available, whether local knowledge or scientifically established. Data for the biodiversity component are discussed in Section 5.2 to illustrate the principles of our approach in this particular forum. Data supporting guidelines advocated by other groups will receive equivalent attention, but are not discussed in this paper.

Agreement on mapping units. LUPIS$^+$ can work only with a single land classification for all candidate land uses. Negotiation and compromise on boundaries and resolution are needed so that, for example, agricultural and conservation land uses are both accommodated. Attributes are necessarily assumed to be homogeneous across mapping units. In the case of remnant vegetation and conservation plantings, the conservation value of a mapping unit is the sum of the contributions of all vegetation patches and strips in a mapping unit. Factors affecting the choice of mapping units include the resolution at which data are available, and the scales of the different candidate land uses. In New South Wales the mapping units will be based on soil landscapes. In Victoria a land facet classification is used, where a facet is a subdivision of a land system. Neither of these units corresponds with land use, paddock or property boundaries. This is an advantage because, as we have argued already, the process is not intended to produce a land use plan for the catchment, and a system that uses natural boundaries is less threatening to landholders than one that uses fence-lines. And by using biophysical rather than property boundaries, the heterogeneity of the land is revealed, and with it opportunities for diversification at property and catchment scales.

Estimation of ratings and suitability scores. A rating is the estimation of the suitability of a mapping unit for a land use in terms of a single guideline. Ratings can be quantitative or categorical. Quantitative ratings can be expressed as levels or as continuous functions. Participants' votes are applied to the ratings and combined in LUPIS$^+$ to produce suitability scores for each land use, defined as:

$$\text{suitability score} = \sum r_{ijk} v_k$$

where:

r_{ijk} is the rating representing the ability of the mapping unit i (i = 1, I) to satisfy guideline k (k = 1, K) when assigned land use j (i = 1, J)

v_k is the guideline importance vote required to gain an achievement level for guideline k that is acceptable to participants

ratings are defined to span an interval of 0 to 1; the higher the value, the more highly valued the mapping unit is from the perspective of the guideline

suitability scores can be standardised across land uses to allow for the different numbers of guidelines applied to the various land uses

the suitability score represents each land unit's relative value for a specified land use.

This linear combination approach is regarded by Hogarth (1980) as robust.

Maps of suitability scores can be generated for each land use across the hierarchy, and guidelines, rating algorithms and votes can be adjusted until participants are satisfied that the suitability maps reflect their perceptions.

Land use maps and diagrams. Suitability scores drive the allocation of land uses to mapping units not affected by exclusions or commitments. The land use (or set of compatible uses) with the highest suitability score is the one allocated. An initial land use map provides a starting point for the negotiations that are necessary for the realisation of win–win opportunities and the achievement of efficiency gains.

Negotiation. Several negotiation tools are available. For example:
- Identification of 'hotspots' — mapping units where the suitability scores of land uses advocated by competing groups are all high. These are places where negotiation effort can be concentrated effectively, rather than dissipating it on territorial disputes over land where there is little competition.
- Guideline achievement is reported in percentage or absolute values (the area allocated), so participants can monitor progress towards the goals of their group.
- Consensus land allocation — here the objective is to arrive at an efficient allocation that enables each group of participants to maximise their individual objectives while still being mindful of the competing objectives of other participants.

Guidelines and data layers

In our Heartlands and Ecosystem Services work data layers will support guidelines for controlling nutrient inputs to streams, producing crops, livestock and forestry products, storing carbon, enhancing biodiversity and controlling water tables and salinisation. Biodiversity is discussed below to illustrate our approach.

Biodiversity guidelines for land use allocations

Measuring the biodiversity of a catchment – the variety of genes, species, and ecological communities – is not feasible. Work in Victoria and NSW has recognised this by developing partial measures (GBCMA 2000; NRE 1997, 2002; Berwick 2001; Oliver 2002; Parkes et al. 2003), or surrogates (Margules and Redhead 1995). In Victoria these are based on:
- the representativeness and complementarity at bio-regional scale of native vegetation remnants of ecological vegetation classes (EVCs)
- the condition of remnants relative to a benchmark
- their vulnerability, or susceptibility to threats, for example because the ratio of edge length to patch area is high, or weed invasion is likely because of high soil fertility and position low in the landscape
- their degree of connection to neighbouring patches
- their responsiveness to management.

LUPIS$^+$ guidelines will address each of these partial measures, with others that reflect state policy on rare or threatened species.

Guidelines can be framed within existing statutes (e.g. the *Flora and Fauna Guarantee Act 1988, Planning and Environment Act 1987*) and policies (e.g. Victoria's Biodiversity Strategy (NRE 1997). The Native Vegetation Management Framework (NRE 2002) and Draft Goulburn–Broken Native Vegetation Plan (GBCMA 2000) provide targets for vegetation cover, representativeness, vegetation condition and viability of threatened species. These strategies also set out principles for management of vegetation and a hierarchy of priorities for actions which can be used to developed guidelines to address complementarity and spatial interdependencies (Bennett and Ford 1997).

Additional guidelines can be supplied by participants. These can address issues specific to the particular subcatchment, such as susceptibility to salinisation. Guidelines addressing the potential of vegetation restoration to improve its conservation value will be incorporated into the analysis (Ryan 2000). A guideline that links restoration activities as a cost function will be developed to allow participants to determine the type and level of restoration activities undertaken to achieve desired goals given resource constraints or trade-offs with other actions (Lambeck 1997).

Biodiversity data

The data employed in the LUPIS+ exercise are determined by the guidelines. They include:

- *Conservation status*. This is derived from the EVC vegetation classification system (NRE 2000, Berwick 2001). EVCs are groupings of floristic communities derived from stratified surveys in each bioregion. Each EVC has been mapped by NRE and current extents compared with pre-European distributions with each EVC assigned to a Conservation Status within each Bioregion based on remaining extent, inherent rarity and degree of threat (NRE 2000).
- *Remnant configuration*. Size, shape, edge to area ratios, neighbourhood and isolation measures of native vegetation, and total cover within each mapping unit, are estimated.

Dynamic catchments

In pursuing our research priorities we have learned much about social and ecological patterns, processes and change. It has become clear that while it is relatively easy to set a vision for a more efficient land use pattern, it is much harder to envisage the stages through which it might be reached. Land use patterns have always been dynamic, and as they have changed so has their efficiency and equity. LUPIS+ is able to produce a sequence of land use patterns for, say, 5, 10, 20 and 50 years from now. We envisage that the maps would be used adaptively by communities and agencies, modifying them as circumstances, values, objectives and information change. It is apparent that we need to add another criterion to the list in section 2 — the ability to explore transitional stages and the changes in benefits and costs along the way — an ability already built into LUPIS+.

Acknowledements

We thank Jim Crosthwaite and an anonymous referee for the contributions they made to the logic and clarity of our paper.

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