Emerging environmental markets: A Catchment Modelling Framework to meet new information requirements

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Abstract

This paper reports on a Catchment Modelling Framework (CMF) designed to support an Australian pilot (*EcoTender*) of an auction for multiple environmental outcomes. The CMF is used to estimate *multiple* environmental outcomes including carbon, terrestrial biodiversity, aquatic function (water quality and quantity) and saline land area, information which was previously unavailable for application to environmental markets. This is the first time a market-based policy has been fully integrated from desk to field with a Catchment Modelling Framework for the purchase of multiple outcomes. The CMF incorporates a suite of one-dimensional plant-based models that are explicitly linked to a fully distributed 3D-groundwater model. This framework solves the *missing information* problem of linking paddock scale landuse and management to catchment scale environmental outcomes. The framework also incorporates a number of biodiversity algorithms that estimate current and future eco-system benefits. This framework provides the Victorian government with a replicable transparent evidence-based approach to the procurement of environment outcomes. The framework can be applied in any location if data are available for calibration and validation.

Introduction

In open, decentralised economies markets are the primary institution through which individuals/firms engage in transactions that create value. Within the economic system, these individuals/firms search for transactions that maximise their private or collective well-being.

Markets have not, however, evolved in all areas of the economy. Even though markets are missing in some areas this does not diminish the need for individuals to engage in value creating transactions - it is just that markets have not taken root to facilitate these transactions. The usual approach in these situations has been for government to step in with command and control approaches. This has traditionally defined the scope of government activities and we observe a strong presence of government in sectors such as the environment, health, education etc.

Where markets for the environment are missing or inefficient economists argue that the welfare of society is reduced. Generally this is observed as a fall in income but in the case of the environment, it means that total well being is diminished. If markets are missing for environmental goods and services, resources are likely to be over-allocated to exploitative activities, such as land clearing (where there are clear signals to investors), and under-allocated to conservation activities (eg. nature conservation). Understanding why markets have not evolved to deal with the environment is an important step in designing mechanisms and developing the information required to support them for an efficient allocation of resources to the conservation of environmental goods and services.

It is commonly understood that markets fail because of the public good nature of environmental goods and services. Individuals do not own environmental amenities such as clean air or water – they are *non-appropriable.* They are also *non-rival,* so that enjoyment of the environment by one individual does not preclude enjoyment by others. Despite these characteristics we know that many individuals are willing to pay for an increase in environmental goods. Potential *demanders* of environmental goods and services include government on behalf of society and groups of individuals such as farmers who want to protect their land from environmental threats (ie. salinity).

There are many opportunities to invest in activities that supply these goods and services – given appropriate incentives and information, many landholders could change land-use in ways that will increase the supply of bundles of environmental goods and services. Where there are willing buyers and willing sellers intuition suggests that a deal will be of benefit to both groups. In economics terms, we know that these exchanges are the basis of wealth creation in society, but have not been possible for many environmental goods and services.

Bardsley *et al.* (2002) notes that ideas about why markets are missing or inefficient have changed over time. The authors note that Coase (1937) identified ‘transaction costs’ as the main obstacle to the existence of markets. While poorly defined property rights are generally recognised as the major impediment to transactions, more recent ideas in economics suggest that asymmetric information and aggregation problems are also important factors in explaining the non-existence of markets. It is now known that information problems lie at the root of most missing markets. The basic reason that asymmetric information destroys markets is that it is hazardous to do business with someone who has relevant but hidden information.

Akerlof (1970) showed that the existence of asymmetric information (that is, where one party is informed about aspects of the economic problem and the other is not) can render some seemingly competitive markets inefficient. In the limit, this phenomenon can result in the non-existence of markets. The uninformed party, in many environmental problems, is liable to be exploited, and may be unwilling to participate. Akerlof demonstrates that the demander of the goods in risks purchasing a ‘lemon’, because they don’t have sufficient information describing the good, which the seller possesses. In order to reduce the risk when purchasing environmental goods it is important to be able to define and measure them. On the demand side of the environmental market there has scientific information is needed to help define and measure environment goods and services.

Latacz-Lohmann and Van der Hamsvoort (1997) explain how information asymmetry affects the functioning of markets for environmental goods and services associated with private land. They note that there is a “clear presence of information asymmetry in that farmers know better than the program administrator about how participation (in conservation actions) would affect their production plans and profit”. On the supply side of the environmental market there is a lack of information about the cost of the goods.

It follows then that markets should be able to be created by addressing these information problems. By attending to a) mechanisms that reveal information from landholders (mechanism format and design) and b) disclosure of scientific information to inform purchasers about the quantum of services provided by landholders.

Stoneham *et al.* (2003) address these information problems and show it is possible to create a market. They conclude, “The pilot auction (BushTender) has shown that it is possible to create at least the supply side of a market for nature conservation and in conjunction with a defined budget, prices can be discovered and resources allocated. Characterising nature conservation on private land as a problem of asymmetric information has improved our understanding of why this and related environmental markets are missing or ineffective and has introduced an alternative policy mechanism to those currently available." Further, this approach demonstrated that cost savings of up to 7 times are achievable when compared with previous grant based systems in the same area. BushTender focused on one environmental outcome, terrestrial biodiversity, for which the “*habitat hectare*” approach was applied along with other biodiversity-related information to help solve the missing scientific information problem (Parkes *et al*. 2003).

In the context of environmental problems this suggests that markets for some environmental goods and services might be created if relevant information is discovered and shared between demanders and suppliers of these goods and services.

A better understanding about missing information problems that have been preventing markets from evolving for environmental goods has prompted both the research and development of the information required (linking landuse change with environmental outcomes) and the mechanisms needed to reveal other information (costs) needed for value creating transactions to occur.

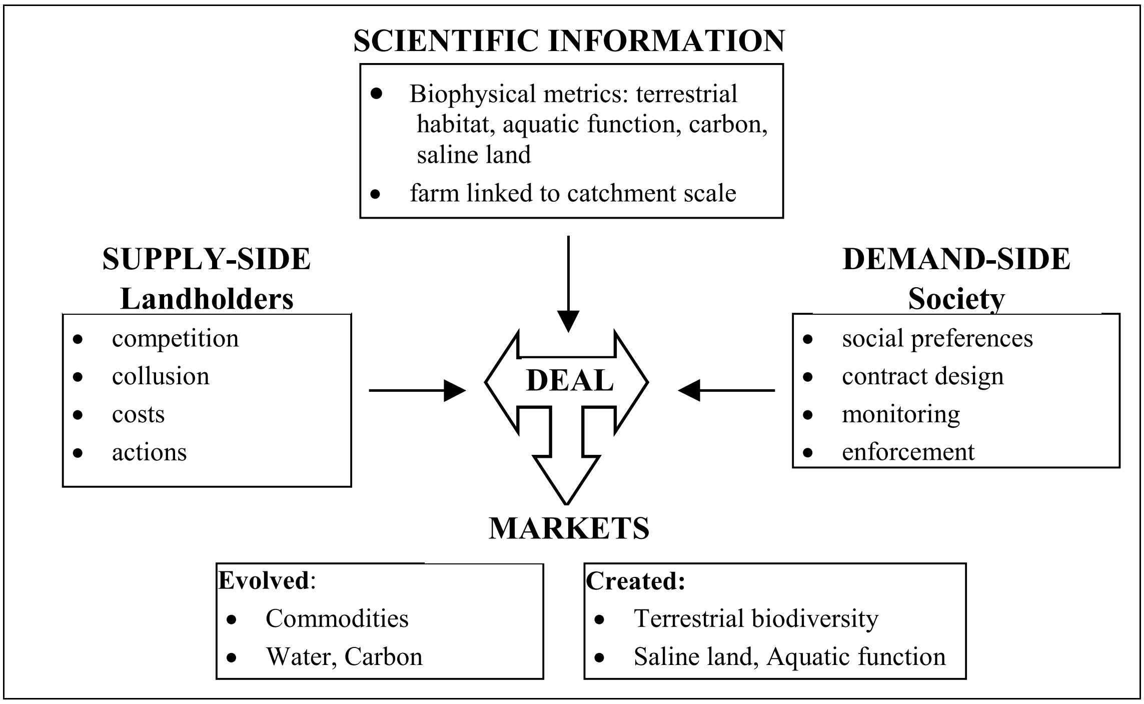
This paper concentrates on the development of new information focusing primarily on informing the demand side of the environmental market. It is assumed that the information asymmetry’s with respect to cost on the supply side have been dealt with by Stoneham et al 2003. However, their pilot was limited to one environmental good, where the information system developed here will deal with multiple environmental goods.

Redesigning Markets: New Information

The basic idea behind the research reported in this paper is that markets for environmental goods and services related to private land can be created if the underlying information problems are resolved. Figure 1 illustrates information that is relevant to the formation of markets for environmental goods and services and the players that hold this information. As noted by Latacz-Lohmann and Van der Hamsvoort, landholders hold information about the supply cost of changing land use or management (opportunity cost). Scientists hold information about the biophysical impact of changing land use and society holds information about the value of these goods and services (willingness to pay).

Auctions can be designed to coerce these landholders into revealing relevant cost information, supply prices will be discovered and resources allocated, as is the case with other markets. The scope to complete transactions (the "DEAL" in Figure 1) between society (demanding more environmental goods and services) and the private landholder (supplying environmental goods and services) represents the market for environmental goods and services. Striking a fair deal between society and the landholder is the objective of the institutional design problem. Society should not be asked to pay more than the competitive supply price and landholders will only supply environmental goods and services if they are adequately rewarded for the resources diverted from other uses of land. Further, society wants to understand what it is paying for in order to express preferences for alternative environmental goods and services and allocate budget. Society needs information that measures and describes the environmental goods and services.

Figure 1. Information Framework



The choice of mechanism (auction, subsidy) is the primary driver for achieving cost effective purchase of environmental good and services. Stoneham et al (2003) argues that auctions are a cost-effective mechanism and are effective in overcoming the asymmetric information problem. However, independent of the mechanism chosen, cost effectiveness can be improved by improving the scientific information about the quantum of environmental goods and services.

A number of studies have suggested that conservation programs using a range of mechanisms (grants, taxes) have been inefficient because they have focused on on-site information rather than environmental outcomes (Ribaudo 1986, Wu and Bogess 1999, Wu and Skelton-Groth 2002). For example conservation programs have focused on on-site physical criteria, such as soil erosion and recharge, rather than the benefit to the environment of a reduction in erosion or recharge. Further, there is a growing recognition that environmental outcomes are correlated – benefits are jointly produced by the same action. For instance, revegetation may jointly produce carbon, improvements to water quality and wildlife benefits. Wu and Bogess (1999) refer to this as an ecosystem-based approach that recognises the interaction between alternative environmental benefits. They show that an efficient fund allocation must account for both physical production relationships between environmental outcomes and the value (to the environment) of those outcomes.

The Catchment Modelling Framework (CMF) presented in this paper focuses on providing the missing information linking environmental outcomes with actions on private land. The framework provides empirical estimates of correlations between environmental outcomes and explicitly links on-site landuse changes with off-site environmental outcomes. The framework has been designed to explicitly model and report the joint production of environmental outcomes which links effectively with policy to more efficiently allocate conservation funds.

This paper reports on the methods used and information generated from biophysical models developed and adapted to provide information needed to support a market for environmental goods and services associated with private land. It reports on the information needed to conduct a pilot multiple-outcome auction (EcoTender) where the purchaser is concerned with the impact of land-use change for four environmental dimensions (carbon sequestration, aquatic function, saline land and terrestrial biodiversity). The Catchment Modelling Framework is used to develop and present preliminary results for each of the environmental outcomes followed by a discussion and conclusions.

Catchment Modelling Framework

The auction approach explicitly recognises the heterogenous nature of landholders opportunity costs and the environmental outcomes they may produce. Past modelling approaches have adopted large homogenous land areas assuming the environmental outcomes within an area are the same for all landholders. Aggregated approaches are not suitable for application to the auction and do not allow for a comparison of environmental outcomes at the farm scale.

The Catchment Modelling Framework (CMF) was developed because no other approaches provided farming systems models that operated at the catchment scale and are explicitly linked to groundwater (Beverly *et al*., 2003, Eigenraam *et al*., 2005). Further, they do not provide transparent estimates of environmental outcomes nor the ability to combine biophysical information into environmental outcomes in a systematic manner. The CMF can estimate multiple environmental outcomes and spatially represent these to potential bidders and the purchaser (Victorian Government) of these services. The CMF models landholder actions at the scale in which they occur – farm/paddock – explicitly accounting for the heterogenous nature of the environmental outcomes.

As heterogeneity between landholders exists it is possible to get more environmental outcomes for a given environmental budget. This approach offers the prospect of improving the cost-effectiveness over the single dimension auction by maximising the total of environmental benefits per dollar. It also reduces the costs of providing information about the impact of land-use change, thereby reducing transaction costs associated with procuring environmental outcomes.

The CMF incorporates a suite of one-dimensional farming systems models into a catchment scale framework with modification to account for lateral flow/recharge partitioning. The CMF consists of an interface and a simulation environment. The interface is used to assemble time-series and spatial data sets for use by simulation models, visualisation and interpretation of data, and the interrogation of simulation outputs. The interface was designed to assist in both the pre- and post-processing of spatial and temporal data sets.

The interface is also used to apply rule-based methods to analyse landscape features. For instance, remnant native vegetation maps showing current coverage are used to assess the spatial significance of alternative revegetation options. Generally, this type of analysis is rule based (ie. patch size and shape, connectivity of remnant patches, distance from sources of refuge such as river corridors or sources of replenishment such as large patches of native vegetation,). In most cases the rules are developed based on current understanding of the spatial needs of relevant species and coded into the interface for application in different catchments. The interface was developed using MATLAB (a commercially available software) and can be distributed as an executable to non-technical users and stakeholders.

The simulation environment is an assemblage of one-dimensional farming systems models capable of simulating pasture, crop, trees and a fully distributed 3-dimensional groundwater model. The simulation environment has been designed to produce scripts that automate the process of employing third party software, MODFLOW. The CMF simulates daily soil/water/plant interactions, overland water flow processes, soil loss, carbon sequestration and water contribution to stream flow from both lateral flow (overland flow and interflow) and groundwater discharge (base flow to stream). The agronomic models can be applied to any combination of soil type, climate, topography and land practice. Using the interface, outputs from these simulations can be compiled for visualisation, interpretation and interrogation.

The CMF develops both a surface element network and a groundwater mesh based on unique combinations of spatial data layers. Typically the spatial data necessary to derive the surface element network includes soil, topography, landuse and climate. The groundwater model requires spatial data pertaining to aquifer stratigraphy such as the elevations of the top and basement of each aquifer, spatially varying aquifer properties and river/drainage cadastral information. Additional data includes time-series records of stream flow, groundwater hydrograph, groundwater pumping, and irrigation.

Outputs from the model can be characterised based on scale as either specific to the management scale (paddock/farm) or the sub-catchment to catchment scale. Simulations predict soil/water/plant interactions on a daily basis providing a comprehensive range of time-series outputs for each surface element. These include:

- complete water/soil balance (soil moisture, soil evaporation, transpiration, deep drainage, runoff, erosion),
- vegetation dynamics (crop/plantation yield, forest stem diameter, forest density, carbon accumulation).

At the sub-catchment to catchment scale outputs include:

- stream dynamics (water quantity and salt loads);
- groundwater dynamics (depth to watertable, aquifer interactions, groundwater discharge to land surface and stream).

The following section outlines how the CMF is used for the development and application of environmental outcomes adopted in the pilot study.

Estimating environmental outcomes

Modelled outputs from the CMF need to be presented so purchasers (in this case the State government) can express their preferences for different quantities of environmental outcomes. Such investment decisions are often further complicated by the need to compare a range of actions across broad landscapes and different ecosystem types that may produce varying amounts of different outcomes of dissimilar intrinsic value.

The CMF needs to be able to systematically provide measures of environmental outcome that:

- incorporate the inherently different functional characteristics of different ecosystems
- integrate the joint production characteristics of environmental outcomes resulting from one action, and
- account for both the physical production relationships between environmental outcomes and the relative environmental value of those outcomes.

Building on these concepts, the EcoTender pilot uses an information framework that defines each environmental "outcome" in terms of 'service' or the change in the level of function resulting from the landholder actions and the "significance" of the change.

To estimate the change in level of function, it is necessary to have a standard reference point against which change is measured. Adapting the policy approach applied in Victoria for assessing conservation status of biodiversity assets (NRE 2002), it was decided to use pre-1750 as the "natural benchmark" against which current ecosystem function and change in function arising from landholder management actions in the catchment can be assessed. Under such an approach, the pre-1750 landscape is modelled using the assumed pre-European settlement vegetation types to provide an understanding of native vegetation cover both current and prior to clearing. The current and pre-1750 modelled landscapes can then be used to measure changes in landscape function resulting from landholder interventions based on a progression towards

1750. In this context, the pre-1750 “function” is not a target but simply a reference point for measuring change. The pre-1750 benchmark approach is also used to estimate the change in native vegetation quality or extent resulting from landholder actions (see below).

Actions

For simplicity and ease of testing landholder actions in the pilot are limited to indigenous revegetation and improved remnant native vegetation management. In the future other on-farm management actions can be evaluated but further research is required to determine appropriate monitoring and enforcement strategies.

Revegetation requires the establishment of indigenous species in formerly cleared areas to achieve required target based on the modelled pre-1750 vegetation types for the site. Remnant native vegetation management involves landholder commitments that improve the vegetation quality of the site as assessed in comparison to a ‘benchmark’ that represents the average characteristics of a mature and apparently long-undisturbed state for the *same* vegetation type (Parkes *et al*. 2003, DSE 2004).

Indigenous Revegetation

Revegetation is limited to Ecological Vegetation Classes (EVC) (Table 1 below shows examples from the total 38 used) based on the pre-1750 vegetation maps of the region (Woodgate *et al*. 1996, Parkes *et al*. 2003, DSE 2004). EVCs are the level at which native vegetation has been mapped across Victoria. In general, EVCs are defined by a combination of floristics, life form, position in the landscape and an inferred fidelity to particular environmental attributes. This requires that landholders agree to minimum standards including type, species and target densities (based on an EVC benchmark), site preparation and follow-up management.

Table 1: Examples of EVC groupings applied by the model.

Bioregion	Description	Trees (p/ha)	Large Shrub (p/ha)	Medium Shrub (p/ha)	Small Shrub (p/ha)	Large Tufted Graminoid (p/ha)	Total (p/ha)
Goldfields	Heathy Dry Forest	100	50	1000	1500	500	2650
Goldfields	Heathy Woodland	50	0	1200	2000	0	3250
Goldfields	Floodplain Riparian Woodland	50	50	200	100	500	400
Goldfields	Box Ironbark Forest	100	0	1000	500	0	1600
Goldfields	Grassy Woodland	50	0	600	500	500	1150
Wimmera	Ridged Plains mallee	50	0	200	1000	500	1250
Wimmera	Semi-arid Woodland	50	0	600	2000	0	2650
Wimmera	Lignum Wetland	0	0	800	0	0	800

Where:

p/ha – plants per hectare
Trees = overstorey species (usually > 10m tall)
Large shrubs = sub-canopy species > 5m tall
Medium shrubs = shrubs 1-5m tall
Small shrubs = shrubs 0.2-1m tall
Large tufted Graminoid = non-woody grass-like plants > 1m tall

To evaluate the change in each outcome the catchment model was calibrated to pre-1750 EVC vegetation cover and extent and simulations were undertaken for 44 years based on 1957-2000 historical climate data. Each of the EVC types (Table 1) was characterised on the basis of varying root depth, root densities and over and understorey canopy dynamics.

Remnant Native Vegetation Management

Remnant native vegetation is defined as established vegetation of a type (EVC) relevant to that which existed in 1750, prior to settlement and clearing. The aim of remnant native vegetation management is to improve the anticipated future condition of the vegetation through landholder commitments that maintain and/or improve the quality of indigenous vegetation on the site. This may include foregoing entitled uses such as firewood harvesting and grazing (fencing) or active management beyond current obligations under legislation such as weed control, pest animal control and supplementary planting of understorey species.

Outcomes

An output is the direct result of an action as estimated using the CMF. For instance, the action of replacing pasture with indigenous trees results in a measurable output such as a reduction in recharge at the site. In the context of this project we are interested in the outcomes that would result from the restoration and maintenance of remnant vegetation including a reduction in recharge – thus the importance of connectivity within the landscape. For example we are interested in whether a fall in recharge will contribute to reducing the amount of saturated land or whether it will reduce the amount of saline water entering a stream as base-flow.

For example will the fall in recharge contribute to reducing the amount of saturated land or reduce the amount of saline water entering a stream as base-flow.

The outcome used to assess the bids is limited by available scientific information. For instance, a reduction in recharge can be described in the following steps.

1) Fall in recharge
2) Fall in saline discharge to stream from groundwater
3) Reduced impact on riverine flora and fauna
4) Followed by an assessment of the significance of the flora and fauna within the context of local and regional stream networks. The final outcome could be an aggregate of the service provided to riverine flora and fauna, adjusted for river significance.

Currently there is very limited data available to complete steps 3 and 4. In order to score an outcome it is usually assumed that there is a positive relationship between steps 2 and 3 and the measure used at step 2 is an accurate proxy for 3.

Estimating the outcome is a more appropriate measure of the impacts of land use/management intervention. Essentially this is because the outputs (1 above) may be homogenous and are not a good proxy for the outcome – which is the objective we wish to influence. For instance there may be two sites located within a catchment and recharge is estimated to fall by 40mm due to revegetation for both. However, the outcome we are interested in is a fall in saline discharge to stream, to improve aquatic flora and fauna. When the outcome is calculated as the change in saline discharge to stream, the recharge results in a fall of 10mm and 25mm. Even though the change measured at the sites was the same (40mm) they are now different at the stream. There may be a number of reasons for this including, location in the catchment with respect to the stream, soil type, groundwater characteristic and slope. By measuring the outcome rather than using proxies, this pilot is focused on improving the quality/quantity of landscape elements thereby meeting environmental objectives.

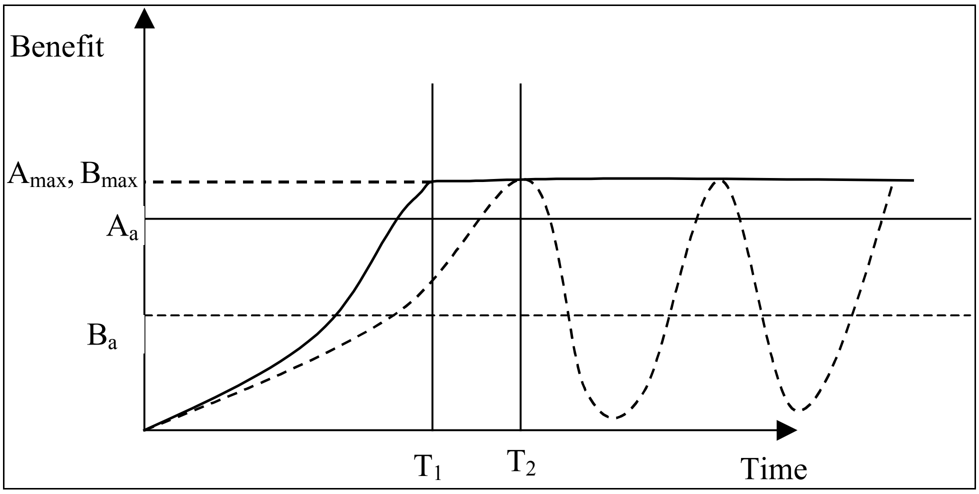
Stock and flows

The outcomes that result from land use change or management actions need to be assessed as either a change in stock or a change in flow. For instance, a reduction in recharge may result in less saturated land affected by rising groundwater when the water table has reached a new equilibrium. The change in saturated land at equilibrium is the benefit of intervention – a reduction in the stock of saturated land. Alternatively the change in saturated land could be viewed as a flow of benefits through time. As the water table approaches equilibrium there is less and less saturated land until equilibrium is reached. On reaching equilibrium there is a constant flow of benefits – the change in saturated land equivalent to the change in stock measure of saturated land.

If all actions resulted in a permanent and instantaneous change, it is possible to compare benefits based on changes in stock. However, if the form of intervention results in a time dependant outcome they may be more accurately compared based on the flows.

Figure 2 below shows the outcome resulting from two actions with respect to time. Action A is revegetation with native species and action B is revegetation with commercial forestry with harvesting at regular intervals. Action A provides increasing benefits up to T1 reaching a maximum of A_{max}, and remaining at A_{max}. Action B provides increasing benefits up to B_{max} (where $A_{max} = B_{max}$) but then declines following harvest and rises back up to B_{max}. The decline in benefits from action B arises when the trees are harvested. Typically this type of benefit flow is observed for groundwater discharge and carbon accumulation.

Figure 2. Benefit flows and time



For action A equilibrium was reached at T1 and for action B a temporary equilibrium was reached at T2. If the actions were compared as stocks at T2 they would be evaluated as having equal benefit, A_{max}. However, this approach does not account for the variability of the benefits provided through time by action B after time period T2.

Instead, if the actions are compared as the average benefit at a point in time greater than T2 the benefits measures would be A_a and B_a resulting in A_a ranked as providing greater benefits than B_a. Instead of using an average, the flow benefits could be discounted to reflect present value. Further research is required to determine the appropriate approach and time periods.

It is assumed that actions in the pilot are permanent in so far that both revegetation and remnant management will be ongoing. Further, the nature of the actions results in a continuous flow of benefits up to a maximum similar to example A – revegetation. Therefore when applying the CMF to determine the change in outcome a steady state solution was adopted to estimate the long term equilibrium condition under the altered vegetation/management regime.

Steady state approach to estimating outcomes

The predominant driver of groundwater flows and levels, is rainfall and in turn the recharge it creates. After long periods of high rainfall the soil reaches a point were it is saturated and there is a subsequent increase in recharge. Soil type, slope and vegetation determine the level of recharge. Groundwater levels determine the amount of saline land (land within 2 meters of the groundwater, see below of detail) which is considered and important environmental outcome. If the groundwater level is fluctuating through time then the area of saline land will also be changing. In order to measure a change in saline land area a steady state is defined where the groundwater is no longer fluctuating and saline land area is constant.

The steady state solution derived using the CMF model represents the long-term equilibrium condition within the pilot region arising from locally modified vegetation/management regimes. This condition exists when the water table si no longer fluctuating and saline land area is constant.

The CMF can be used to derive a steady state in two ways. Firstly the CMF can be run over a long time horizon whilst observing the variation in groundwater flows and level. When the variation between successive periods reaches a user-defined threshold (based on a minimum variance between current and last period or past average), then both the inflows/outflows and groundwater levels can be reported as representing steady state conditions. In turn the amount of land within 2 metres can be reported to estimate the environmental outcome. The level of variance a user is willing to accept determines the steady state solution.

Issues with this approach include computational time, climatic variations between years and the lag time between water entering and leaving the groundwater system. Further, if there is a prolonged period of either high or low rainfall the system may be exhibiting steady state properties (low variance) however it is a product of the rainfall/recharge. This is particularly noticeable for extended low rainfall periods when groundwater inflows (recharge) are very low or next to zero and outflows are constant for long periods. This would exhibit itself as a local (short-term) solution rather than a global (long-term) solution.

The second approach adopted for in pilot involves calculating the long run (approximately 40 years) average recharge and applying this to the groundwater system. This removes the rainfall/recharge variation and allows for the calculation of the steady state groundwater flows and level. The long run average recharge and surface flows in used as the input to the groundwater model and the steady state solution is then run until the groundwater has reached equilibrium. This approach overcomes the local solution issue and requires much less computational time.

Saline land

Saline or saturated land is commonly defined as the area of land where the depth-to-watertable is less than 2 meters. The groundwater height was estimated using the CMF model and the area of land classified as saturated or impacted by waterlogging was defined as those regions where surface elevation (based on a digital elevation model) less groundwater height was within 2 metres. The service score is the change in saturated land area (ha). The metric for change in saline land is the sum of the change in land area within 0.1, 0.5, 0.8, 1.0, 1.5, 2.0 m of the groundwater. The steady state approach is used to estimate the area of land.

The significance can be determined by the importance of that land within the catchment context. For example under current conditions there may be 525 ha classified as saturated. Following the implementation of the action, the amount of saturated land is reduced to 515 ha – the service score is 10ha. The significance of the 10ha is determined based on current use. For instance the 10ha may include cropping, roads, buildings and wetlands. However, in order to determine the overall significance preferences need to be explicitly expressed for each land type. Preference information was not available in a form that could be applied systematically in the pilot. Rather preferences for the pilot have been expressed as an equal weighting for each land type, reducing the outcome score for saline land to change in area alone. That is, the final metric for saline land is the fall in hectares of land within 2 metres of the water table.

Aquatic Function

Aquatic function is particularly challenging because it needs to take into account groundwater (GW) flows to stream, surface water (SW) flows to stream and the quality of both. SW and GW steady-state contributions to stream were calculated for both pre-1750 EVC coverage and current land use. The SW volumes were based on both the surface and sub-surface lateral flow contributions to stream. The GW contribution to stream includes groundwater loss to stream and groundwater discharge volumes to surface, and in turn to stream.

To assess the impact on in-stream biodiversity it was necessary to consider the relative volume and quality of SW and GW streamflow contributions. However currently there is very little science available to provide repeatable and transparent interpretations of the impacts on flora and fauna due to various flow regimes and varying ratios of SW and GW streamflow contributions. Therefore the following approach was adopted and is an adaptation or extension of the steady state principle used for the saturated land area assessment. It is recognised that this approach has been developed in the absence of clear scientific relationships between surface water flows to stream and pollutants and their relative impact on riverine flora and fauna.

Within the pilot catchment the groundwater is saline and it was assumed that a fall in saline emissions to stream may provide a benefit to the flora and fauna. Similarly, a fall in surface water arriving at stream was assumed to reduce the amount of nitrogen, phosphorous and sediment, which benefits riverine for flora and fauna. Further a change in flow timing and magnitude towards pre-1750 conditions was assumed beneficial to riverine health.

The modelled pre-1750 landscape assumes that in-stream biodiversity in the pilot catchments were adapted to the prevailing conditions at that time as determined by the contributions from ground water and surface water. That the greatest change in these elements under current practice is due to surface water contribution indicates that a reduction in SW contribution to stream is considered of greater importance than that of GW. Further to this, SW contributions to stream have altered the timing of peak and low flow periods and the temperature of the water – both of which contribute to the viability of in-stream biodiversity.

Currently within the CMF it is possible to examine the temporal aspects for changes in water volume with and between years however nutrients are not reported. As a proxy for nutrients changes in erosion arriving at stream are reported and combined with the changes in water. As such, the final metric used in the pilot for aquatic function is the product of water quantity (sum of both SW and GW mm/annum) by erosion (t/ha).

Terrestrial biodiversity

Remnant native vegetation management

Habitat service - There are a number of actions that landholders can take to maintain or improve the condition or extent of habitat on private land. These include foregoing entitled uses such as firewood harvesting and grazing; active management of threats beyond current obligations such as control of weeds and pest animals or supplementary planting of species-deficient areas. The value of these actions can be expressed as a Habitat Services Score (HSS) where HSS_i represents the change in quality and quantity of habitat at a Site “i”. The Habitat Services Score (HSS) measures the amount of terrestrial biodiversity improvement offered by the various landholder management commitments.

Biodiversity significance - Landscapes that have been modified for agricultural purposes will not necessarily retain a representative mix of habitat types and will generally contain biodiversity assets at varying levels of depletion and naturalness. One way of expressing the conservation value of different sites is with a Biodiversity Significance Score (BSS) where BSS_i represents the biodiversity value of ‘*Site i*’.

The BSS rates each site according to its conservation value. The BSS depends on the type and quality of native vegetation on the site and its relative conservation status (using EVCs that have been assigned a bio-regional conservation status such as endangered, vulnerable, depleted or rare.), the plants and animals that may use the site as habitat, and the position of the site in the broader landscape and its contribution to maintaining or improving the regional native vegetation context for a range of important mobile fauna species.

Conservation status is determined using concepts of rarity and degree of threat (NRE 2002). Vegetation quality uses the ‘habitat hectares’ approach of Parkes et al. 2003, which assesses the vegetation according to a number of site-based attributes (e.g. tree cover, understorey diversity and cover, weediness, amount of regeneration, amount of organic material etc.) and a number of local landscape attributes (size of patch and amount and configuration of surrounding native vegetation).

Each of the site-based attributes is assessed and scored against a benchmark that represents the average characteristics of a mature and apparently long-undisturbed state for the same vegetation type (Parkes *et al*. 2003). The landscape context (LC) score for each site is determined using a mathematical algorithm that provides a measure of the current amount and relative distribution of native vegetation within the vicinity of the site (Ferwerda 2003). The landscape context algorithm is based on the general principles that large, round patches (high area : perimeter ratios) provide the best opportunity for ecological processes to be maintained; and remnants that are surrounded by other remnants or connected to larger remnants by 'links' or 'stepping stones' provide better habitat opportunities than isolated remnants.

The landscape context (LC) layer is combined with some additional spatial rules to derive the Biodiversity Landscape Preference (BLP) layer. The LC layer is weighted to reflect those parts of the landscape where both the requirement for restoration and "function" of native vegetation restoration activities are optimised. These are typically areas located between the most intact landscapes where the functionality of restoration is greatest but where the requirement for restoration is least, and the most fragmented landscapes where the requirement for restoration is greatest but the functionality of restoration is least. The weighted LC layer is combined with rules relating to patch size and shape, connectivity of remnant patches, distance from sources of refuge such as river corridors or sources of replenishment such as large patches of native vegetation to derive the BLP. These rules have been derived based on current understanding of the future spatial needs of key mobile fauna species.

The BLP layer is effectively an assessment of the future spatial considerations of restoration. It provides a relative preference for different parts of the landscape as a measure of their potential role in restoring broader landscape function.

The BSS uses information held in corporate (government) databases, LC and BLP maps and site-based information to verify what is on the site. The metric used in the pilot is the product of HSS and BSS.

Revegetation

The scoring of revegetation is similar to remnant native vegetation management. The service score is determined by a combination of size of the site and its impact on the amount and configuration of native vegetation in the local landscape and the estimated change in vegetation condition of the site. The former is a measure of the change in landscape context (LC) resulting from the revegetation while the latter applies a fixed score to revegetation that meets a minimum required standard based on the EVC benchmark.

The significance score uses the same approach as remnant native vegetation management except that the role of the site as habitat for plants and animals is not assessed. The metric used in the pilot is the product of HSS and BSS.

Carbon

The carbon outcome is calculated for each site by estimating the change in accumulated carbon (t/ha) between the current condition and the established EVC at maturity. Accumulated carbon is calculated using biomass production specific to each vegetation class. Both the benchmark and current condition account for different spatial vegetative cover, canopy, soil type and root development for each vegetative class.

There is no significance measure for carbon because it is a diffuse pollutant. However, the location significance of the revegetation is captured in the significance scoring of terrestrial biodiversity. The metric used in the pilot is the tonnes of carbon sequestered at each site.

The following table summarises the outcomes used in the pilot.

Table 2. Summary of outcomes, service and significance

Attribute	Change in level of service	Desirable change	Significance
Terrestrial Biodiversity	Δ habitat score (habitat maintained or improved per ha)	Increase	Biodiversity conservation significance , threatened species conservation status, habitat quality, landscape preference
Aquatic function	Δ water "quality" (tonnes of soil / ha to stream) Δ water quantity (mm of water / ha to stream)	Decrease	(not in pilot)
Saline land area	Δ saline land (ha with groundwater < 2m)	Decrease	can discriminate - but equal weighting in pilot
Carbon sequestration	Δ carbon sequestered (tonnes / ha)	Increase	n/a

Total environmental outcome

The pre-1750 benchmark was also used to calculate the final aggregate score. For each of the environmental outcomes the pre-1750 and current stock of each outcome was calculated under steady state conditions (see Table 3 below).

Table 3. Pre-1750 and current environment outcome stocks

Environmental outcome	Pre-1750 stock	Current stock	Difference
Habitat hectare[1]	418,140	19,081	399,059
Saline land area (<2m)	83,702	127,153	43,451
Aquatic function	27,070	94,320	67,250

1) Applied to both remnant management and revegetation

For each site assessed in the auction equation (1) was applied to determine the aggregate score.

$$Total\ Score = \left(\frac{A_i}{D_A} + \frac{S_i}{D_S} + \frac{B_i}{D_B} \right) * 100 \qquad \text{(i)}$$

where:

A_i, S_i and B_i are the aquatic, saline and biodiversity outcomes for site i

D_A, D_S and D_B are the aquatic, saline and biodiversity differences from Table 3 above

In effect the above equation calculates the total percentage movement towards pre-1750 conditions for each of the environmental outcomes.

Carbon is dealt with as a market good and landholders are paid separately for each unit produced. The selection of bids is based only on the Total Score and the cost of the bid, farmers adjust their bid given the knowledge they will receive carbon payments if their bid is accepted.

Pilot Areas

The pilot was run in two sub-catchments in Victoria, namely the Avon Richardson (371,000ha) and Cornella (47,000ha) (Figure 3). Catchment selection was based on data availability, the areal extent of any proposed land use change, the type of management considered by land managers and a requirement that the focus catchment be a priority region as identified by the appropriate state authorities. The landscape also needed to be topographically and climatically variable and the catchment also needed to be unregulated (not controlled by in-stream structures and no diversions for other uses such as irrigation) and monitored so as to provide continuous stream-flow and water quality data to underpin model calibration and validation. Additionally, catchment selection was based on the presence and quality of time-series groundwater observation data, which is used to conceptualise and validate the groundwater dynamics.

The current landuse in the Avon Richardson comprises 52% cropping, 37% grazing, 6% trees and the remaining 5% constituting urban infrastructure and water bodies. Annual rainfall ranges from 350 to 765 mm/year. In contrast the current landuse in the Cornella catchment comprises 53% cropping, 26% grazing, 20% trees and the remaining 1% constituting urban infrastructure and water bodies. Annual rainfall ranges from 450 to 670 mm/year.

Figure 3. Pilot areas

For each spatial vegetation coverage, discrete land units across the catchment were defined based on soil, slope, climate, landuse, land management and elevation. Each land unit varied in size ranging between several hectares to tens of hectares and was connected to an underlying groundwater model. Assigned to each land unit was a biophysical farming system model simulating daily soil/water/plant interactions.

The calibration procedure adopted a split sample test with non-overlapping calibration and verification periods. The calibration strategy was applied to pre-scenario conditions between 1957 and 1995 whereas model verification was assessed on data measured between 1996 and 2000 inclusive.

Calibration of the framework was based on matching measured salt export, stream dynamics, selected groundwater hydrograph responses, depth-to-watertable information and mapped groundwater discharge areas. Stream flow analysis techniques were applied to measured stream gauge data to derive quickflow (overland, sub-surface and groundwater surface discharge) and groundwater baseflow (groundwater flows into streams) estimates. The calibration criterion compared these quickflow and baseflow time-series data sets with predicted volumes to calculate goodness of fit based on 44 years of historical climate data.

In the case of the Avon-Richardson catchment, the simulated area of groundwater discharge was 16,200 ha which was in agreement with the mapped 15,500 ha. Groundwater mean annual baseflow was simulated to be in the order 250-300 ML/year, which was also in agreement with gauged stream flow data. The validation process of the CMF has produced results consistent with measured stream flow and recharge estimates (Beverly *et al*., 2003, Paydar and Gallant, 2003, Tuteja *et al*., 2003, 2004).

Results

The following results are limited to pre-implementation, as field application commenced in early June 2005 and final assessments are not currently available. In order to present preliminary results the CMF was used to assess outcomes in terms of saline land area, aquatic function, soil loss (erosion) and terrestrial biodiversity under both current and pre-1750 landuse. The pre-1750 condition was based on Ecological Vegetation Class (EVC) description of vegetation cover (Parkes and Newell, 2003, see Table 1 above). The CMF systematically simulated the impact of changing landuse to pre-1750 on 25ha parcels (there are approximately 14,975 parcels in the Avon-Rchardson.) of land across the entire catchment whilst assigning current landuse to all other land units.

A parcel of any size could have been simulated but it was thought that 25ha was reasonable for communication to farmers about the idea that area matters when trying to maximise the environmental outcomes for their actions. The resultant spatial information is also used to provide a context for impact to farmers. Figure 4 below is as example of the type of spatial information used for communication with farmers.

It should be noted that the magnitude of the changes are not linear in so far that, the sum of the impacts arising from landuse change on any two parcels may result in a greater change than the addition of the impacts derived from each parcel. That is to say outcomes are area and spatially dependent. The distribution and magnitude of results reported here would be different if smaller or larger parcels of land were simulated. Given the non-linear nature of the results with respect to area and location it is important to calculate the outcomes for each site once it is mapped by field staff. During pilot implementation each site is evaluated taking into account its unique size and location within the catchment. Basing bid selections on *a priori* modelling information may over or under estimate the benefits of any given site and reduce the cost effectiveness of the auction as a whole. The results for the each environmental outcome are presented below.

Aquatic function

For aquatic function the predicted SW and GW contributions to stream were calculated under steady state for both pre-1750 coverage and current land use across the entire catchment. The SW is based on both the surface and sub-surface lateral flow contributions to stream. The GW contribution to stream includes groundwater loss to stream and groundwater discharge volumes to surface, and in turn to stream. Modelled results indicate that changing landuse to pre-1750 condition across the entire catchment would result in a 19,800 ML/year reduction in lateral flow to stream relative to current condition (see Table 4 below).

Table 4. SW and GW contribution to stream, EVC pre-1750 and current landuse

Catchment coverage	Surface water contribution to stream (GL/year)	Ground water contribution to stream (GL/year)	Mean annual total stream flow (GL/year)
EVC pre-1750	7.3	12.5	19.8
Current landuse	26.4	54.6	81
Percent change (pre-1750)	+72%	+77%	75%

Table 4 shows the predicted SW and GW contributions to stream under current and pre-1750 conditions. Notably there has been a significant increase in both flow regimes relative to pre-1750 conditions. Surface water flows increased by 72% due to tree clearing and the introduction of pasture and annual cropping enterprises. There has been a correspondingly very large increase in groundwater flows to stream (77% increase). Therefore any reduction in surface water and groundwater contributions to stream, a movement towards pre-1750, is considered desirable (based on the benchmark approach discussed above).

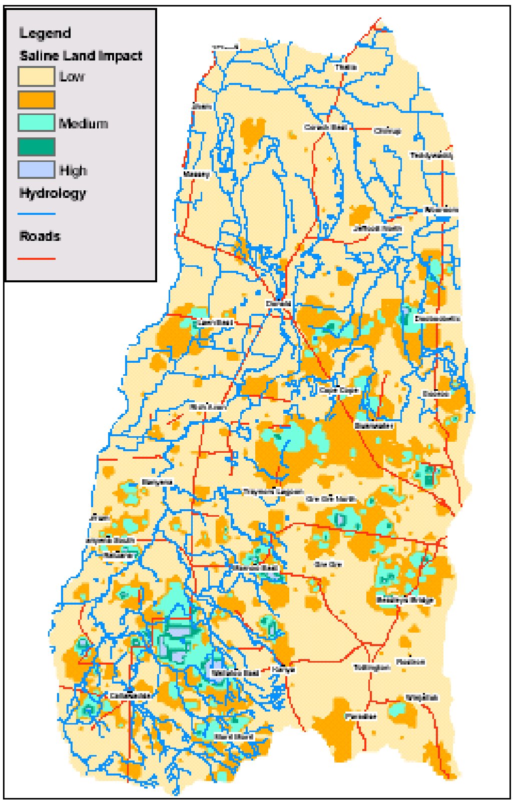
If scientific evidence were available to describe the relative impact of each type of water it may be desirable to attach weights to them based on their contribution to aquatic health. However, for the pilot no weighting's were attached due to limited scientific information about their relative impacts. For each of the 25ha parcels modelled the sum of the change in GW and SW ranged between 0 and 30 ML with an average response of 4.1ML assuming steady state conditions.

In order to reflect changes in water quality estimates of erosion were also obtained. Changes in erosion to stream varied between 0 and 0.36 tonnes per ha/annum. The final aquatic function score is a combination of the change in stream flow (surface water and groundwater) and erosion.

Saline land area

Changing landuse to pre-1750 condition on discrete 25 ha units was predicted to reduce the area of saline land by 8.5ha on average with the maximum impact being approximately 125 ha depending upon landscape position and groundwater characteristics. Figure 4 below shows a map of the variation in impact. This type of map is also used by field officers for communication with farmers to indicate the relative importance of their site (farm) within the landscape.

Figure 4. Change in saline land impact



The predicted groundwater impacts were then compared to the predicted changes in recharge for each site to see wether recharge is an accurate proxy to make decisions about investment in the landscape. Of the

14,975 cells modelled, the correlation was 27% between a change in recharge and a change in saline land area.

The impacts of a change in recharge vary across the catchment as a function of the underlying groundwater characteristics and groundwater flow directions and gradients. For example, simulated results of the impact on groundwater discharge volumes to stream arising from the reintroduction of remnant vegetation show that the greatest impacts are associated with the south-easterly region of the Avon-Richardson catchment. This is not surprising as the groundwater flow direction is in a north-westerly direction such that reafforestation in areas located in the north-westerly portion of the catchment have little impact on groundwater discharge volumes to the dominant river system located in the centre of the catchment. That is, a unit change in recharge (arising from reafforestation) in the north-westerly zones of the catchment have very different impacts relative to a unit change in recharge in the south-easterly regions of the catchment. As a general rule a unit change in recharge will have a different impact on saline land depending on where it occurs in the catchment. This result suggests recharge is not a suitable proxy for investment when considering the off-site impacts (saline land area) of landuse change.

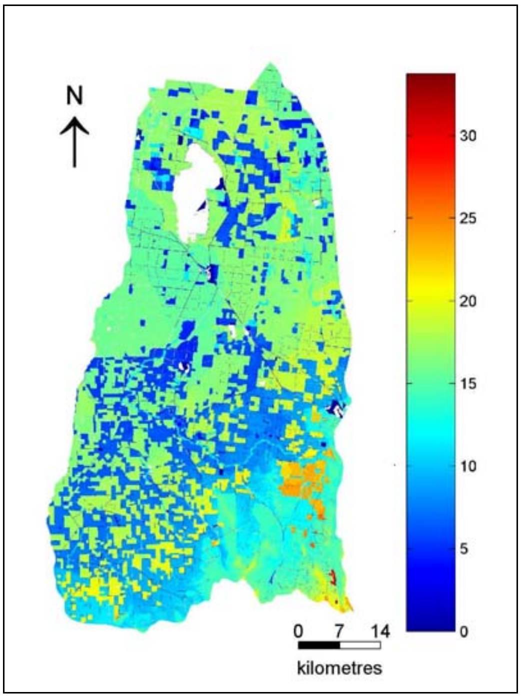
Terrestrial biodiversity

A priori, it is not possible to report the biodiversity outcomes because the habitat service score requires a site visit to determine the current condition of the site and to assess particular biodiversity assets (e.g. habitat for rare or threatened species). However, components of the biodiversity significance score, biodiversity landscape preference (BLP) and landscape context (LC) can be examined because they are modelled using existing information on native vegetation extent and configuration. BLP ranged between 0 and 90 and LC ranged between 0 and 23.

Carbon

Predicted carbon sequestration ranged from 0 to 34 kg/m^2 averaging 13 kg/m^2. The total amount of carbon sequestered is driven primarily by the EVC replacing current practice. Figure 5 below is a map of the change in sequestered carbon (t/ha) arising from replacement of current landuse with pre-1750 vegetation for the Avon Richardson sub-catchment.

Figure 5. Sequestered Carbon



Joint production and heterogenous outcomes

One of the key motivations for developing the CMF was the hypothesis that environmental outcomes are jointly produced and this feature might improve the cost effectiveness of funds allocated to the environment. In order to determine if outcomes are jointly produced a random sample of sites were assessed for saline land, carbon, terrestrial biodiversity and aquatic function. These sites were then sorted to determine whether they were producing more than one outcome – for the single action revegetation. Analysis of the simulation results derived for all sites with the pilot suggest that 73% generate two or more environmental goods supporting the hypothesis that environmental outcomes are jointly produced from a single landuse change.

Given outcomes are jointly produced there may be scope to reduce total costs if outcomes are correlated. For instance the use of one outcome as a proxy for others may reduce the level of model reporting and complexity. This may save time and reduce the transaction costs associated with estimating outcomes. In order to test if outcomes can be used as proxies for one another the outcomes are tested for spatial correlation.

The table below shows the correlation matrix between the metrics for aquatic function, saline land, carbon and the significance indices for terrestrial biodiversity, for the whole catchment.

Table 5. Whole of catchment spatial correlation matrix

	Aquatic Function	Carbon	Saline Land	BLP	LC
Aquatic Function	1				
Carbon	0.17	1			
Saline Land	0.16	0.06	1		
BLB	0.03	-0.07	-0.09	1	
LC	0.09	-0.06	-0.17	0.64	1

Results presented in Table 5 suggest that there is a very low correlation at the catchment scale between outcomes, and as such we would expect a lot of variability in the *total score* (sum of outcomes) reflecting landscape variability. These results support the need to estimate the outcomes for each site during the auction because no assumptions can be made about the level or ratio of outcomes.

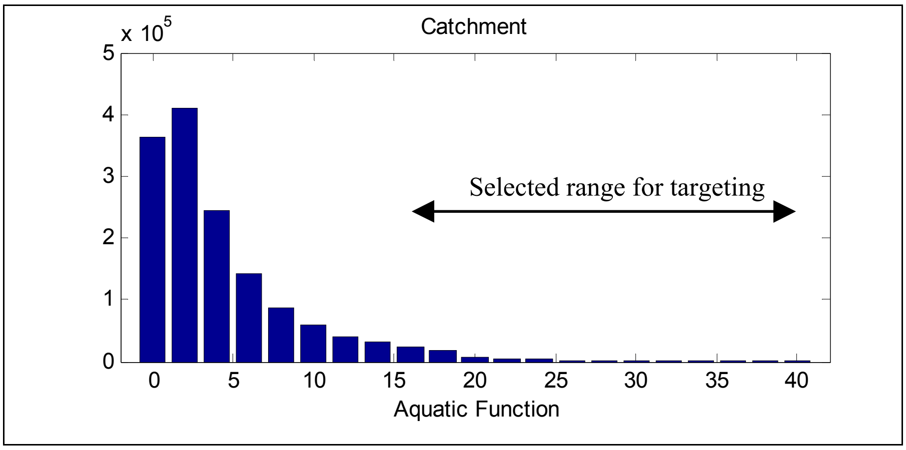
From Table 5 it can be observed that there is a positive correlation (0.17) between carbon and aquatic function. This is due to a number of biophysical factors. Firstly, revegetation generally sequests greater amounts of carbon than current practice and revegetation has a strong influence on surface water dynamics. For instance revegetation reduces surface water runoff, erosion and recharge, all of which are used to calculate the aquatic function outcome. In this pilot results indicate that revegetation produces both carbon and aquatic benefits 17 percent of the time.

BLB and LC are correlated because they are based on the same base data set (spatial location of current native vegetation) but are not identically correlated because they represent different landscape function and attributes. LC is focusing on the current existence whilst BLB focuses on the future impact of terrestrial biodiversity management or revegetation. They are examining different aspects of *eco-system* function, current function and future function given landuse intervention.

The CMF is shown to provide *ex ante* data on expected outcomes. There is a temptation to use this data to target areas with the aim of reducing the number of site/farm visits thereby saving time (reducing costs) or achieving greater outcomes (areas with *ex ante* high outcome scores).

The following is an example of targeting areas of the catchment based on high outcome scores. Figure 6 below shows the histogram for aquatic function outcomes for each site within the catchment (approximately 1.4 million units each of 50*50 metre resolution). Using tools built into the CMF specific areas of the histogram can be remapped by selecting a range.

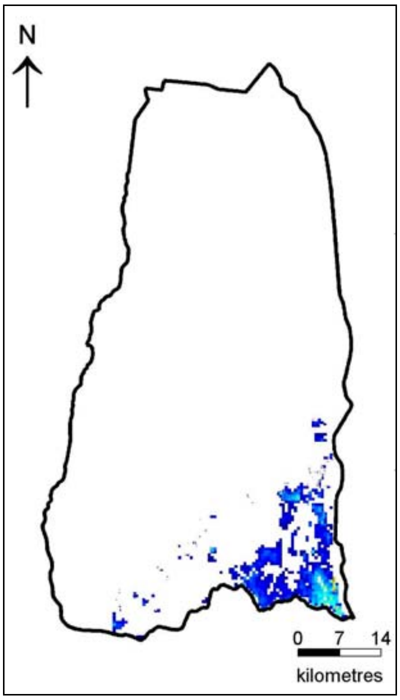
Figure 6. Catchment - Aquatic Function Histogram



For this example land areas that scored aquatic function greater than 15 were mapped to show their location within the catchment (see Figure 7 below). This shows there is a concentration of land in the south east of the catchment scoring high for aquatic function. It may be possible to target these areas for land use change reducing the costs by not visiting other areas of the catchment, were aquatic function the primary outcome of interest. However, it was shown above that there is a very low correlation between outcomes, so targeting this area may reduce the overall quantum of outcomes.

While it may be tempting to target high impact areas the cost of undertaking actions in these areas may be high. It may be possible to target areas with lower aquatic impact at a lower cost, thus reducing the cost per unit outcome. The overall cost for a given level of aquatic function would be lower. The auction approach adopted in the pilot makes the most of both the heterogenous nature of the outcomes and costs.

Figure 7. Targeting high scoring aquatic outcomes



It may be possible to identify other areas with a lower aquatic function score but increase the scores of one or more of the other outcomes, generating greater outcomes in aggregate, assuming the purchaser is indifferent between outcomes.

Implementation and training

A possible barrier to adoption of the CMF is its scientific complexity. The framework needed to be used by field officers either on site or locally. An interface was developed with the field officers that enabled them to down-load site information into the CMF for processing. The interface provided the officers with the ability to validate landuse (both current and proposed), run the biodiversity algorithms and finally report the outcomes.

One field officer was assigned to each sub-catchment and they undertook 8 hours training in the use of the interface. One of the officers had previously conducted single outcome assessments (biodiversity) using a paper based system, which they found to be time consuming with significant potential for error. Further it was very difficult for them to trace the process if bids needed to be altered or for audit purposes. They reported the interface to be non-threatening and there is no longer the need for reams of paper to complete the biodiversity assessment because the CMF had been programmed to complete the process with their input. On average site visits are taking one day to complete. This includes travel, site assessment, post processing data and administration.

Discussion

The CMF has significantly reduced the transaction costs associated with accurately determining environmental outcomes for any site within the landscape. The CMF can be readily calibrated to any catchment providing there is sufficient data for calibration. Further, the framework can be readily updated as new data becomes available.

Generally, fixed-price grants based programs have focused on one environmental outcome and required information to support spatial allocation decisions, or worst still allocate funds based on lowest cost without any consideration of outcomes. The CMF has reduced transaction costs and accounts for multiple environmental outcomes.

The CMF has incorporated biophysical processes to account for erosion, water, carbon, saline land to estimate environmental outcomes. Further the landscape context (LC) considers the current location of native vegetation and the biodiversity landscape preference (BLP) considers the future spatial needs of key mobile fauna species. The CMF is the only framework (the authors are aware of) that has brought together both types of information.

The framework has demonstrated the importance of joint production in environmental outcomes and the heterogenous nature of the landscape in terms of environmental outcomes. This information has been incorporated into an auction-based approach (EcoTender) offering the possibility for significant cost savings.

Results presented in this paper demonstrate that a unit change in recharge (arising from reafforestation) has very different impacts on saline land depending on where it occurs in the catchment As such recharge is not a proxy for saline land area when considering the off-site impacts of landuse change. The use of recharge as a proxy would reduce the cost effectiveness of available environmental funds, if a change saline land area were an objective.

The correlation results presented in Table 5 and those specific to aquatic function (Figure 6 and Figure 7) indicate that the CMF is capable of exploring the trade-offs between environmental outcomes. However, targeting areas based on outcomes alone, ignores the cost side of the problem. It may be the case that all high cost land use changes are located in south east of the catchment. If cost effectiveness is the objective (minimising the total cost per unit outcome) then it may be beneficial to go elsewhere in the landscape.

It is not until the cost information is available that a decision can be made about the most cost-effective distribution of funds across the catchment. Using outcome information alone may result in much higher total costs.

Interpreting the biophysical information into economic costs – for instance converting yields to opportunity cost – is tempting but potentially very costly, as it ignores the heterogenous nature of landholders costs. In many instances biophysical information has been used to estimate costs for targeting purposes.

Data from previous auctions for conservation contracts show that when landholders were engaged in a competitive bidding process for conservation contracts, their bids displayed much larger variation than can be explained by variation in land capability (Stoneham *et al*., 2003). The average bid per hectare in BushTender was \$274/ha but the standard deviation of bids was \$349/ha. Whilst there was some variation in the quality of land between bidders, the auction was confined to a relatively homogeneous (with respect to agricultural production) Box Iron Bark vegetation classification. This result is significant because it means that the cost of land-use change is different on each farm and this information needs to be truthfully revealed rather than estimated using bio-economic models that treat landholders as homogeneous agents.

If outcomes are appropriately developed to reflect the importance of location now and in the future and account for all on-site and off-site impacts, the remaining exercise is to employ a mechanism that reveals the true cost of making the changes, hence the use of auctions.

The CMF was developed to support a pilot project and as such, there are a number of areas that would benefit from further research and effort. From an economic point of view there has been no account for diminishing returns or preferences between outcomes. The framework has shown the dependency between spatial locations for individual sites but has not included empirical approaches (for instance synergies between sites) to exploit the opportunity for further cost savings.

In the pilot areas water is not used for productive purposes. A reduction in stream flows could have deleterious economic impacts if the water is collected and used for productive purposes. There are a number of policy issues associated with the need to address the trade-off between water for environmental purposes and water for productive or consumptive purposes if this approach were to be adopted in an area used for water collection. However, the CMF provides the information needed to implement of test policy options.

Conclusion

The methodology developed in this study links landuse and management with biophysical crop growth and environmental processes on a site-specific basis with the capacity to assess the off-site impacts at both the farm and sub-catchment scales. This approach accounts for spatial variability and connectivity within the landscape.

Results presented in this paper demonstrate the value of adopting a holistic catchment modelling framework to inform a market-based auction process. The project si applying the CMF to estimate multiple environmental outcomes, both on-site (biodiversity, erosion and carbon sequestration) and off-site (catchment yield and water quality), arising from landuse change at the farm scale.

The framework has shown that recharge alone is not a suitable metric for the allocation of environmental funds for the prevention of saline land. Further the CMF has shown that targeting a single outcome is not sufficient to capture the heterogeneity of landscape change at the farm scale. Combining this information with auctions for landuse change provides the opportunity to purchase environmental outcomes more cost effectively than current grant based approaches.

The Catchment Modelling Framework provides policy makers with a new tool to analyse landscape intervention and make informed decisions about the outcomes resulting from investment at the paddock scale. The framework is practical and feasible for application in the field and provides a cost effective, replicable and transparent method for the assessment of environmental outcomes to support programs for the allocation of environmental funds.

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