Challenges Encountered During Integrated Modelling Across Multiple Catchments

Neville D. Crossman

Brett A. Bryan

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Policy and Economic Research Unit, CSIRO Land and Water, PMB2, Glen Osmond, South Australia, Australia, 5064.

Abstract: There has been a recent trend in natural resource management decision making toward target setting and the use of models to identify geographic priorities to meet those targets. However, measurable and quantitative targets for assessing progress toward achieving management and policy goals tend not to be established. This may be due in large part to a lack of clarity in data and model availability, and geographic prioritisation processes. The long history of extensive human activity and modification of natural resources in the Murray Darling Basin of southern Australia has led to a myriad of natural resource management problems, particularly dryland salinity and biodiversity decline. The Lower Murray Landscapes Futures (LMLF) project was conceived in recognition of the need to urgently reverse the declining state of the region through better informed natural resource management planning, policy and decision making. The LMLF project is a multi-organisation and multi-catchment effort to apply integrated natural resource management within the lower Murray Darling Basin. A central component is the integration of social, economic and biophysical research methods and models and a synthesis and expansion of targets. The aim of this paper is to highlight lessons learned from efforts to integrate targets, models and decision support tools for natural resource management policy and planning. Challenges have arisen during the project, particularly during data preparation, model design, and in the production of outputs suitable for communicating to a wide and varied audience.

Keywords: natural resource management policy; quantitative spatial data analysis; integrated modelling; decision support.

1. INTRODUCTION

Management is required to address the widespread degradation of natural biological, land, water and climatic resources. The emerging paradigm of integrated natural resource management (INRM) provides a framework for assessing and prioritizing the management of multiple natural resource objectives [Bellamy et al., 1999]. INRM also involves the integration of political, economic, technological and social aspects of natural resource management [Bellamy et al., 1999]. The Lower Murray Landscapes Futures (LMLF) project was conceived in recognition of the need to urgently reverse the declining state of the region (Figure 1) through better informed INRM planning, policy and decision making.

The LMLF (Figure 1) extends across three catchments: the South Australian Murray Darling Basin (SAMDB 56,000 km^2); the Mallee Catchment Management Authority (39,000 km^2), and; the Wimmera Catchment Management Authority (23,500 km^2). Nearly 200,000 people live in the region. High value agricultural production, including irrigated agriculture, dryland cereals and grazing stock, is the main staple.

The requirement for sound research and planning within a clear objectives/targets-based framework is highlighted across much of the recent INRM literature [e.g. Slocombe, 1998; Bellamy et al., 1999; Edvardsson, 2004]. Many regional INRM agencies in Australia have developed, or are in the process of developing, INRM plans to identify the major environmental assets and threatening processes operating in their region. The centerpiece of these regional INRM plans and investment strategies is a set of aspirational (long-term) targets and associated resource condition (medium-term) and management action (short-term) targets that are used as measure of progress. Many Australian INRM groups have developed investment strategies for prioritising the actions required to address the targets.

Specifically, we see four main barriers to prioritising investment in INRM actions within a target-based approach to natural resource management, specifically:

1. Resource condition targets can be refined and enhanced by considering established scientific principles and biophysical processes based on quantitative data.
2. The ability to measure the achievement of resource condition targets is highly dependent upon data availability.
3. Resource condition targets lack the specificity required to identify geographic investment priorities for INRM actions.
4. The ability of policy instruments to encourage INRM actions and the economic feasibility of achieving resource condition targets is often not explicitly considered.

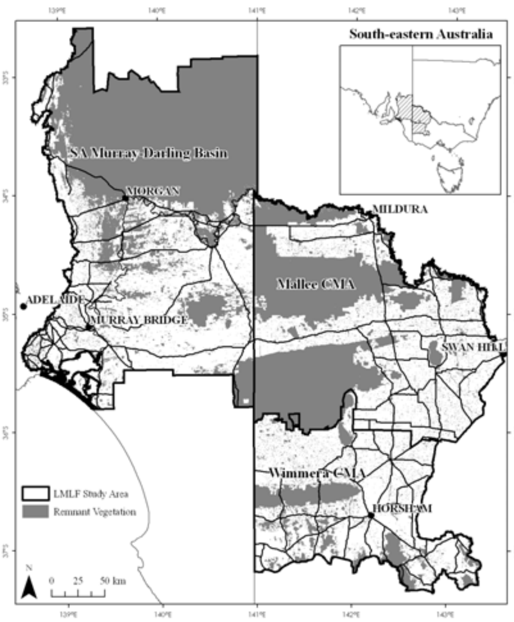

Figure 1: LMLF study area.

This paper is centred on integrated modelling and prioritisation that works toward overcoming these barriers. We begin by examining and synthesising INRM targets found with the multitude of INRM Plans applicable to the region. We then briefly discuss existing models that can be used to measure progress against targets within an integrated planning and policy framework in the LMLF study area. Data requirements for modelling and decision-making are discussed. The paper contains reflections on the lessons learned during this project, specifically examining applicability of integrated modelling and decision support for natural resource management and policy.

2. SYNTHESIS OF INRM TARGETS

For this study we are particularly interested in native vegetation management and revegetation on priority private lands as well as dryland farming practices that improve the condition of soil and water resources. It was necessary to synthesise the existing 1200+ INRM targets into a set of explicit and quantitative targets.

Many of the existing targets read as broad qualitative statements and therefore cannot be used to set geographic priorities for meeting resource condition targets. While they act as overarching goals, or guiding principles (e.g.: *To bring about a significant improvement in the condition and health of the native vegetation and biodiversity within the catchment*), they contain limited tangible or explicit information about how much and where the natural resource is managed.

We distil relevant existing quantitative aspirations and targets into a set of quantifiable targets for assessment and modelling (Table 1). Looking at Table 1 it is evident that a limited number of targets contain a quantifiable element. They describe either an areal or proportional goal. Bryan et al. [2005] found that regional targets are rarely based on ecological, biophysical or conservation planning principles [Margules and Pressey, 2000; Crossman and Bryan, 2006]. Nor do they explicitly consider economic realities such as the opportunity cost from forgone production when the change to a new land use (e.g. from grazing to revegetation using local indigenous species) does not generate income. Furthermore, there is little consistency in targets between regions (Table 1). Hence, the challenge was to develop a consistent, revised and expanded set of quantitative targets that contain both existing quantitative areal and proportional goals, as well as clearly defined ecological, conservation and economic goals (Table 2).

Our solution was to develop a 2-level hierarchical set of targets (Table 2). At the top level are the LMLF-wide goals that universally apply to the study area. These goals are imposed on the Systematic Regional Planning geographic allocation model developed by Bryan et al. [2005], via a set of attributes that drive model solutions toward lower cost alternatives. Cost in this case is a function of spatial and economic attributes. The second level of target hierarchy is the set of constraints imposed on the model that vary according to existing sub-catchment targets (Table 1).

Table 1: Existing quantitative targets extracted from INRM Plans relevant to the LMLF region.

Action and target (*and region*)

Revegetation with local native species

- Increase cover of each Ecological Vegetation Class (EVC) to **15%** of pre-European extent. (*Mallee*)
- **30%** cover across each bioregion. (*Mallee*)
- **750ha** per year revegetation of priority EVCs. (*Wimmera*)
- Increase cover by **1%** in agricultural region by **2020**. (*SAMDB*)
- Re-establish **950ha** of vegetation to provide links in priority areas by **2006**. (*SAMDB*)

Protect and improve remnant vegetation

- Improve condition of **20%** across all conservation significance levels. (*Mallee*)
- **750ha** of high quality remnants protected per year. (*Wimmera*)
- **500ha** of low-medium quality remnants protected per year. (*Wimmera*)
- Protect and enhance **10,000ha** of vegetation by **2006/07**. (*SAMDB*)
- **50%** of 6 specific threatened communities protected by **2006**. (*SAMDB*)
- Increase area of priority vegetation protected to >**2,000ha** by **2006**. (*SAMDB*)
- Improve condition of **50%** of vegetation on private land by **2020**. (*SAMDB*)

Sustainable farming systems

- Reduce land threatened by salinisation from **10%** to **8%** of total land surface. (*Mallee*)
- **20%** reduction in groundwater recharge from farming systems. (*Mallee*)
- Negligible erosion **6** out of **10** years. (*Mallee*)
- Confine eroding land to **3%** in dry years. (*Mallee*)
- **5%** increase in sustainable land management techniques by **2007**. (*Wimmera*)
- Improve dryland WUE by **70%** by **2020**. (*SAMDB*)
- Constrain salt affected land to **120,000ha** by **2020**. (*SAMDB*)
- Establish **25,000ha** of *perennial* vegetation by **2006/07**. (*SAMDB*)
- **40%** reduction in agricultural land at risk of wind erosion in each June by **2020**. (*SAMDB*)

The new targets (Table 2) contain the quantifiable elements of existing NRM targets in the LMLF, but have been expanded to include the conservation planning principles of representativeness, persistence, and efficiency [Margules and Pressey, 2000], and of integrated natural resource management. Representativeness is incorporated by prioritising for on-ground management those vegetation communities and biophysical zones that display disproportionately high levels of disturbance. Persistence is captured using measures of habitat size, shape and configuration. Efficiency stipulates that the targets be met in the most cost effective ways using economic estimates of opportunity cost and returns from alternative farming systems. Principles of INRM are incorporated through the integration of other degrading processes such as dryland salinity and wind erosion.

3. SPATIAL DATA REQUIREMENTS

Clearly much quantitative data is required to spatially prioritise on-ground actions that meet the INRM targets in Table 2. Compiling, synthesising and integrating the many disparate and inconsistent datasets into a useful package for modelling were the next challenges.

Different State Governments collect spatial data using different standards and methodologies, leading to the challenge of data precision. For example, native vegetation in the South Australian (SAMDB) and Victorian (Wimmera and Mallee) parts of the LMLF has been mapped at a very fine scale in the latter (individual tree resolution and very complex shapes) but at coarser scale in the former (patches > 1ha). The Victorian component contains approximately 209,000 polygons describing vegetation communities, compared to approximately 31,000 polygons in the South Australian part, despite there being similar levels of vegetation cover across comparable geographic extents. The large and detailed Victorian dataset presented inconsistencies with the coarser South Australian equivalent, which would cause erroneous modelling and decision-making, as well as slow model processing.

The problem of data precision was overcome through use of a smoothing filter that had the effect of removing the many small polygons (< 1ha) as well as removing boundary complexity. Overall the total area of vegetation cover in the Victorian component was almost identical before and after smoothing.

Another challenge was deciding on data resolution. Modelling outputs are intended to serve as a clear guide to the prioritisation of on-ground works that meet INRM targets. Hence sites selected need to be concise enough to identify specific locations, be applicable at the farm-scale, be tangible and quantifiable, but also be of a resolution suitable for modelling (i.e. not be such a high resolution so as to produce unmanageable datasets). We examined the scale of available data, considered the geographic extent of the study area, the scale at which on-ground decisions are made and the data handling and processing ability of the models. Based on these factors we converted all input datasets into 1ha resolution grids for modelling. This resolution preserves spatial detail and specificity, but does not result in datasets to large to process within models.

While detailed methods of data compilation, construction and manipulation are beyond the scope of this paper, the methods are based on established principles. Much pre- and post-processing and derivation of new attributes and datasets was required to develop a package of data that could be used to prioritise toward meeting IRNM targets.

Table 2: Expanded and enhanced set of quantitative targets for INRM in the study area. This list includes existing targets in concordance with existing INRM plans.

LMLF-wide attributes	**Catchment-wide constraints**
Vegetation management	
• Bigger remnant patches are better • Simple shapes are better • Least fragmented are better • Further from patch edge better • Higher risk patches are better • Lower opportunity cost better • Higher wind erosion potential better	Short-term (by 2006-08): • Protect and enhance **10,000ha** (including **50%** of **6** threatened communities) in the **SAMDB**; **750ha** of high quality and **500ha** of low-medium quality remnants in the **Wimmera**, and; **20%** of remnants in the **Mallee**. • Must work toward a **30%** representative target of each EVC/Veg community, climate zone, bioregion and soil land system Medium-term (by 2020): • Protect and enhance **50%** of remnants on private land in the **SAMDB**, and **11,250ha** of high quality and **7,500ha** of low-medium quality remnants in the **Wimmera**. • Achieve a **30%** representative target of each EVC/Veg community, climate zone, bioregion and soil land system.
Revegetation with local natives	
• Closer to remnant vegetation is better • Closer to higher risk patches are better • Lower opportunity cost better • Higher wind erosion potential better • Higher salinity risk better	Short-term (by 2006-08): • Establish **950ha** in the **SAMDB**; **750ha** in priority EVCs in the **Wimmera**, and; **30%** cover across each bioregion and **15%** cover in each pre-Euro EVC in the **Mallee**. • Must work toward a **30%** representative target of each pre-Euro EVC/Veg community, climate zone, bioregion and soil land system. Medium-term (by 2020): • Increase cover by **1%** in agricultural region of **SAMDB**, and **11,250ha** in high priority EVCs in the **Wimmera**. • Achieve a **30%** representative target of each pre-Euro EVC/Veg community, climate zone, bioregion and soil land system.
Sustainable farming systems	
• Higher wind erosion potential better • Higher salinity risk better • Higher deep drainage risk better • Lower opportunity costs are better	Short-term (by 2006-08): • Reduce salinisation threat from **10%** to **8%** and confine eroding land to **3%** of total land surface in **Mallee**, and establish **25,000ha** of perennial vegetation in the **SAMDB**. Medium-term (by 2020): • Constrain salt affected land to **120,000ha**, improve dryland WUE by **70%** and reduce wind erosion risk land by **40%** in the **SAMDB**.

4. INTEGRATED MODELLING

The next challenge in the project was to develop models and data that identify geographic priorities for natural resource management actions (e.g. revegetation, protect remnant vegetation, change farming systems) that meet and measure progress against targets. However, due to limited project timeframes and budgets we applied and integrated existing models and frameworks to overcome this challenge and to fill data gaps. Integrating existing models provides a significant project management benefit through increased R&D efficiency.

Existing models applicable to the LMLF study area were integrated within a GIS-based spatial allocation framework called Systematic Regional Planning (SRP) [Bryan et al., 2005]. Spatial allocation using SRP is implemented within a spatial multi-criteria decision analysis (MCDA) [Malczewski, 1999] framework which provides a structured approach to analysing complex decisions like those required in planning for INRM. Briefly, the existing models we used include:

1. Test outputs from the Agricultural Production Systems Simulator model (APSIM) [see Keating et al., 2003]. APSIM integrates modules of cropping, management and biophysical processes within farming systems for improved decision support.
2. Spatial outputs from the decision support Land Use Impact Model (LUIM) [see MacEwan et al., 2004]. LUIM uses a Bayesian framework to calculate risk to remnant vegetation based on surrounding land use and the inherent vulnerability of the vegetation.
3. Spatial outputs from the salinity impact model (SIMPACT) [see Miles et al., 2001]. SIMPACT uses a GIS to model the impact on river salinity levels given a change in land use, and is based on relationships between soil, groundwater hydrology and rainfall/irrigation.

These models were chosen based on expert advice from project partners and our own modelling expertise. The models generated new datasets for input into SRP. Thus outputs from these separate modelling tools were integrated into a broader decision support framework. Literature on the individual models can be consulted for data development methodologies. Table 3 is a concise list of spatial data used in the LMLF project.

Integration in this paper is applied from another perspective: using models that identify locations for integrated natural resource management. The SRP decision rules used in this study for prioritising locations for INRM actions that most cost-effectively meet multiple targets are based on spatial optimisation using integer programming [Crossman and Bryan, 2006]. Spatial optimisation models select sites (e.g. grid cells) for particular types of INRM actions that minimise or maximise an objective function whilst satisfying certain targets/constraints. For example, the objective function for revegetation using local native species might be to select sites that minimise opportunity cost, wind erosion potential, salinity risk and distance from vegetation patch edge (i.e. LMLF-wide attributes in Table 2), subject to the constraint of 30% representativeness of each vegetation community, climate zone, bioregion and soil land system, and a minimum areal extent of x ha (i.e. Catchment-wide constraints in Table 2).

Table 3: Spatial datasets for geographic prioritisation of INRM actions. See text for full acronym descriptions.

Dataset	**Source**
Revegetation	
Vegetation surrogates (bioregions; estimated pre-clearance vegetation; climate zones; soil classes)	Government
Remnant vegetation	Government
High risk remnant vegetation	LUIM
Landscape fragmentation	SRP
Conservation priority of vegetation surrogates (bioregions; estimated pre-clearance vegetation; climate zones; soil classes)	SRP
Wind erosion and deep drainage risk	APSIM
Contribution to river salinity	SIMPACT
Opportunity cost from lost production	SRP
Vegetation protection and management	
Remnant vegetation and existing protection	Government
High risk remnant vegetation	LUIM
Landscape fragmentation	SRP
Conservation priority of vegetation outside of protection (bioregions; vegetation representativeness; climate zones; soil classes)	SRP
Sustainable farming	
Contribution to river salinity	SIMPACT
Opportunity cost from lost production	SRP
Wind erosion and deep drainage risk	APSIM

SRP outputs consist of a large set of decision alternatives that provide flexibility in implementing geographic priorities. The best alternative can be selected based on the goal of decision makers (e.g. actions are limited to the most cost effective alternative rather than the best option for biodiversity). These alternatives must be presented in a succinct and simple format for ease of digestion by managers and planners in the catchments.

5. CONCLUSION

Challenges have arisen in attempts to integrate and synthesis disparate datasets and models, and the many INRM planning targets across an extensive geographic area such as that in the LMLF study area. The motivation has been to integrate existing modelling tools to develop a prioritisation process for examining cost-effective options for satisfying INRM policy. This form of integration provides benefits through improved R&D efficiency.

The first challenge was the integration and synthesis of INRM targets into a quantifiable set that could be modelled for decision support. The many qualitative targets found in existing INRM plans are not useful in decision support and geographic prioritisation systems. Furthermore there are inconsistencies among catchments making integrated catchment studies difficult. Targets need to be quantitative, measurable, consistent and based on sound principles and available data. They should also take into account broader conservation planning principles [Margules and Pressey, 2000]. Integrated planning for natural resource management also provides many benefits through efficient allocation of resources to actions that achieve multiple outcomes.

The next challenge was integrating models and data. Budget constraints prohibited the development of new models. We used three existing models and the SRP framework to identify priorities that contribute to INRM targets. Although model outputs are not presented here due to space constraints, the SRP framework, and models therein, produce many solutions defined by decision alternatives.

Compiling data that is sourced from geographically distinct sources has also posed challenges. Different government agencies collect data according to different standards and at different scales. This provides a challenge because overly detailed data can skew model outputs, slow model processing and lead to erroneous decision making. Although some detail is lost during smoothing, the outcome is a more manageable and consistent dataset for modelling.

Through overcoming these challenges we now have a robust and succinct modelling framework and package of data for geographic prioritisation of INRM actions across multiple catchments. Targets can be modelled and costed for decision making and policy development. The model framework is currently being applied to the study area and outputs, when reported, will be used by the regional catchment bodies to assist with INRM prioritisation and planning.

6. ACKNOWLEDGEMENTS

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