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Tools for NRM: Linking investments to outcomes

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Abstract: Since the emergence of national natural resource management programs, there have been few tools that can assist regional bodies in planning, monitoring and evaluating the success of investments. Tools are needed to assist natural resource managers in better focusing investments, more efficiently allocating scare resources available to regional bodies and demonstrating ongoing improvements in resource condition. Such tools should also be underpinned by robust scientific analysis and promote enhanced understanding of cause and effect through adaptive learning.

In order to credibly characterize the links between investments and outcomes, we suggest four key steps: a participatory systems thinking approach is needed to define problems; a strong evidence-base is required to further characterise links between cause and effect (e.g. investments and outcomes); sensitivity assessment is required to simplify relationships to the core controlling variables and identify a suite of interventions likely to achieve the desired outcomes; and the impact of interventions need to be updated through a process of adaptive learning, involving follow up monitoring and modelling review.

Clearly, developing such a suite of tools is a substantial exercise. This challenge is the focus of the research hub Landscape Logic (www.landscapelogic.org.au), funded by the Commonwealth Environmental Research Facilities program. In Landscape Logic we are using a suite of tools to link investments to outcomes, through analysis of cause and effect. Our focus issues are water quality and native vegetation condition, linking both social and biophysical processes. We are using conceptual models, retrospective analysis and targeted knowledge collection, to build integration models (Bayesian networks) that sit within a decision support environment. Sensitivity assessment is being used to identify key causality pathways and to simplify complex models. The value of using Bayesian networks lies in their ability to integrate different forms of knowledge across disciplines, identify knowledge gaps and focus new data collection, incorporate the uncertainty inherent in large scale and long term environmental and social processes, and represent knowledge in a form that is useable by decision-makers.

In this paper, we outline a process for linking investment to outcomes via a set of tools, and apply these tools to a case study. The focus of the case study is the Black Box (*Eucalyptus largiflorens*) depression vegetation communities, located on the NSW Murray floodplain. A set of tools were applied to determine the success of a wetland watering program, where a primary outcome was improving the maintenance and regeneration of trees.

Keywords: *Natural resource management, Bayesian networks, sensitivity assessment*

1. INTRODUCTION: NRM ARRANGEMENTS IN AUSTRALIA

Legislative and administrative responsibility for the management of Australia's natural resources rests with State and Territory governments, with the exception of matters of national and international significance. A national audit in 1997 found that despite significant investments in natural resource management (NRM), there were no mechanisms in place to measure changes or trends in the condition of natural resources or land degradation at the landscape scale (ANAO 1997). As a consequence of this, a regional-scale arrangement for NRM planning and investment was pursued. This was formalized in 2000 with the formation of 56 regional bodies across Australia.

The purpose of regionalisation was to facilitate a greater community involvement in NRM planning, priority setting and investment. Regional plans now form the basis for investment, with a focus on target setting, implementation, and cooperative arrangements for catchment-wide activities. Plans address a broad range of issues, including land, water and vegetation management, biodiversity conservation and sustainable agriculture.

To develop and meet NRM objectives, the Australian government invested almost $6 billion between 1996 and 2007. Despite this significant investment, delivery of tangible impacts through the regional arrangements has proved difficult. Audits of public environmental programs (ANAO 2001, 2007, 2008) concluded that it was not possible to gauge the effectiveness of investment as there had been no provision for adequate monitoring of change on the ground. As reviewed in Hajkowicz (2009), although this outcome was not unique to Australia, it fell well short of community and government expectations.

Why has there been little evidence of improvement at the landscape scale despite the scale of investment? (Hajkowicz 2009) argues that part of the problem relates to the 'tyranny of size', where the physical area of landscapes in Australia requiring treatment compared to the size of Australia's economy means that dollars invested per unit area are likely to be low. It must also be acknowledged that NRM problems are plagued by large spatial scales, long time lags between intervention and response and the general lack of any ongoing monitoring of response. These factors make NRM problems classic examples of 'wicked problems' where diverse interests, evolving conceptions of the problem and complexity combine to make problem resolution a challenging process (Rittel and Webber, 1973).

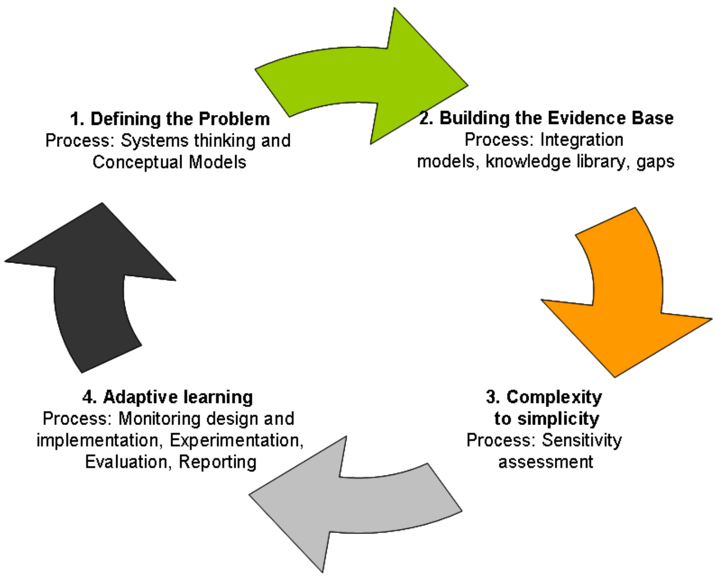

Figure 1. Cycle for linking investments to outcomes

Since the emergence of national natural resource management programs, there have been few tools that can assist regional bodies in planning, monitoring and evaluating the success of investments. We believe that such a set of tools can assist in better focusing investments, more efficiently allocating scare resources available to regional bodies and demonstrating ongoing improvements in resource condition. Such tools should be underpinned by robust scientific analysis and promote enhanced understanding of cause and effect through adaptive learning. Developing such a suite of tools is a substantial exercise. This challenge is the focus of the research hub Landscape Logic (www.landscapelogic.org.au).

In Landscape Logic we are using a suite of tools to link investments to outcomes, through analysis of cause and effect. Such tools include conceptual models, retrospective analysis and targeted knowledge collection, integration models (Bayesian networks) and sensitivity assessment. In this paper, we outline this approach and demonstrate how each of the steps and tools were used to develop a model for the Black Box (*Eucalyptus largiflorens*) community on the New South Wales (NSW) Murray floodplain.

2. BRIDGING THE GAP: TOOLS FOR DECISION-MAKING IN NRM

Bellamy (2001) observed that we lack an over-arching, systematic framework to guide the evaluation of NRM policy. National audits of environmental programs suggest this gap still exists. To meet evaluation needs, we propose a cycle of activities (Figure 1). The first component of the cycle is problem definition. In NRM, problem definition should focus on key system values and define realistic and achievable targets for linking investments to outcomes. This process should be undertaken through participatory processes (Greiner 2004). Once a problem is well defined, an evidence base can be constructed to describe the system. Through sensitivity assessment we can assess uncertainties and identify key pathways for linking investments and outcomes (e.g. the ‘bang for buck’ concept). Via adaptive learning, we can undertake actions and monitor and evaluate outcomes. The steps in the cycle (Figure 1) are explored further below.

2.1. Defining the Problem

To represent and focus complex NRM problems, a systems thinking approach is particularly useful and appropriate. Simon (1955) first pioneered systems thinking as a holistic problem solving process. This approach has now found its way into most branches of resource management and planning, with its emphasis being on objectives, options development, explicit evaluation, implementation, monitoring and review (Simon 1955). Recently, it has been applied within an Australian-based NRM program, Program Logic (http://www.nrm.gov.au/publications/books/capacity-building-planning.html), which aims to provide “a system that links the objectives and instrumental rationale of the policy or program to actual performance on the ground” (Bellamy et al. 2001).

Within Landscape Logic, we focus problem definition on identifying specific targets (which relate to system assets) and causal pathways, where system components and their interactions (e.g. social, biophysical, political) are explored. Targets should represent variables that can be modelled to predict changes over time across environmental gradients for the anticipated management change (i.e. they cannot be broad or generic). We have found that conceptual models or ‘influence diagrams’ are invaluable in capturing a whole of system perspective of an NRM problem, where we engage a diverse group of researchers and stakeholders in the process. We use a simple hierarchy (landscape context > investments > system changes > resource condition) for structuring NRM issues. We use this hierarchy in a ‘bottom up’ fashion, where resource condition is used to bound the suite of preceding variables. Within resource condition, we define a target value, which represents a well articulated and achievable outcome.

This problem definition phase should be undertaken within a broad spectrum of disciplines and stakeholders. This is necessary to ensure that problem definition occurs within an appropriate system boundary, is focused on issues of community concern and avoids bias in the representation of a system. To analyse problems, models that integrate evidence are needed to better understand system complexity and to reduce the ambiguity and subjectivity that can exist in linking cause-and-effect (e.g. investments to outcomes) in NRM.

2.2. Building the Evidence Base

A strong evidence-base is important for characterising NRM problems, planning interventions, monitoring impacts, and evaluating and reporting to funders. Building an evidence-base requires assembling existing knowledge and hypotheses, identifying critical knowledge gaps, and targeting focused data collection and modeling. Such evidence can range from expert knowledge, monitoring data, theoretical concepts to complex quantitative models. The process of assembling an evidence-base should be guided by the outcomes of the problem definition process. In particular, by assembling multiple lines of evidence, we can examine the strength of causality between variables in a conceptual model. To formally integrate and interrogate evidence, we use ‘integration models’. Within the context of modelling, integration can relate to one or several aspects including: the integration of issues, disciplines, methods, models, scales of consideration, and stakeholder concerns (Greiner 2004). Integration models allow us to better characterise complex problems.

Within the context of Landscape Logic, our choice of integration model is Bayesian networks, where models are built using existing data supplemented with targeted data collection to build up an evidence base. The case study outlined in Section 3 also uses a Bayesian Network. Bayesian Network models have already been demonstrated as being particularly useful in NRM (e.g. Pollino et al. 2007a and b). The appeal of using Bayesian networks as integration models is their ability to incorporate different forms of evidence including qualitative and quantitative information, interrogate the evidence through the model building, and identify a suite of interventions likely to achieve the desired outcomes. They are hierarchical models, made up of causal structures and probabilities to quantify interactions between cause (e.g. management intervention) and effect (e.g. vegetation condition). An advantage of using Bayesian networks is their simplicity in describing inherently complex relationships, while avoiding over-representation of mechanistic detail. Nonetheless, the choice of model should be informed by the assessment needs. There are a variety of modelling approaches available for integration and no single modelling tool can be applied to address all NRM issues.

2.3. From Complexity to Simplicity

In ecological models, we seek not to replicate complex systems, but to represent a robust simplification of system behaviour. In models constructed for management purposes, we often want to represent the actions that will achieve a desired outcome or identify the key threats that are impacting on our endpoint. Where possible, it is important in natural resource management to strive for simpler models, as they are easier to comprehend (Iwasa *et al.* 1987) and more amenable to stakeholders. To analyse complex problems and achieve informed simplicity, we often start from a state of confused complexity and use a series of 'tools' to achieve simplicity.

Sensitivity analysis is one type of tool that can be used to determine if complex models can be simplified. It allows us to study how the variation (or uncertainty) in the output of a model can be apportioned to different sources of variation in the input of a model. Through sensitivity analysis, we can begin to identify which variables in our models have the greatest influence on our model endpoints, as well as ordering the importance, strength and relevance of the inputs in determining the variation of the output. Sensitivity assessment begins with sensitivity analysis but extends it to examine which hypotheses about model substructures are consistent with observations of system behaviours and knowledge about the system. It allows one to attempt to discriminate between alternative, outcome-sensitive representations in the model and/or to identify where new information is required to assist that discrimination. It is a powerful tool in model testing and simplification, and we demonstrate this in Section 3 using a Bayesian network.

2.4. Adaptive Learning: Management, Monitoring and Modelling

Adaptive learning is a structured, iterative process that explicitly recognises uncertainty in our understanding and the inherent variability of natural systems. Adaptive management aims to reduce uncertainty over time. The appeal of adaptive management is driven by three factors: that our knowledge of natural systems will always be rudimentary; that systems are in a constant state of disequilibrium; and that community goals and management expectations will always be in flux.

Adaptive management should be applied synergistically with adaptive monitoring and modelling. Adaptive modelling allows us to test the validity of assumptions and hypotheses in decision-making, promotes continual learning as system changes take place and allows monitoring to be targeted at reducing uncertainties, including knowledge gaps, in models. By promoting adaptive management through models, the learning process can be interactive, iterative and meaningful in a positive and constructive way. A major challenge to adaptive management is the time lag between intervention and response.

3. CASE STUDY: LINKING INVESTMENTS TO OUTCOMES – A BLACK BOX EXAMPLE

The case study below describes how a series of tools were applied to develop a vegetation model that explores links between investment, through environmental watering, and outcomes, being improved vegetation maintenance and regeneration. The case study is divided into sections: (a) problem definition; (b) building the evidence base; and (c) progressing from a complex to simple model. The model described was not developed within Landscape Logic. Landscape Logic models are still in the conceptualisation-complex model stage. The case study is used to demonstrate some of the concepts in this paper and the model is fully documented elsewhere (Pollino and Hart 2005).

3.1. Black Box Depressions on the NSW Murray Floodplain

Defining the problem

A risk assessment was initiated within the NSW Murray Irrigation Limited region. The problem definition process (stakeholder interviews and workshop) identified the vegetation community Black Box (*Eucalyptus largiflorens*) depressions and fish communities as being vulnerable (Pollino and Hart 2005). The model, described below, was developed to explore how regional irrigation and landholder activities impact on Black Box depression communities, and whether a local wetland watering initiative was effective in protecting the vegetation communities.

Watering of wetlands on public and private lands is an initiative undertaken by the NSW Murray Wetlands Working Group (an independent, community-based group). The initiative has ecological and social benefits, including improved health of wetlands and educating communities about wetland management (Nias et al. 2003). The group has an environmental water allocation which is used to water wetlands on private and public lands and can be traded to generate program funds. The Black Box depression community, found throughout the NSW Murray floodplain, is a target vegetation community in the wetland watering program.

The construction of the model followed a participatory process. A range of local stakeholder groups were consulted (landholders, irrigation company, state agency and CMA staff, environmental groups, researchers) to define the model scope, develop and refine the model structure and obtain data. Based on stakeholder feedback, the following were theorised as causing a decline in the health of the Black Box depressions:

- Changes to natural hydrology: Some wetlands have been deprived of their natural flooding, while others have been degraded by permanent or near-permanent inundation due to river regulation.
- Salinisation: River regulation, irrigation practices and vegetation clearing are bringing saline groundwater closer to the surface. Wetlands, the lowest areas of the landscape, are usually the first areas affected by shallow watertables.
- Changes to water quality: Water quality changes have been caused by disposal of waste water and poor management of surrounding land.
- Agricultural use: Development of wetland areas for agricultural production may involve removal of vegetation. Excessive stock grazing can impact on the health and regeneration of plant communities.
- Surrounding land use: The management of surrounding areas affects wetland condition through excessive sedimentation and addition of nutrients and agricultural chemicals.

These processes were represented in a conceptual model (not shown). The conceptual model formed the basis of the Bayesian network structure (Figure 2), which has the following components: (1) land management; (2) surface water condition; (3) soil condition; (4) groundwater condition; and (5) and wetting regime. These are integrated into outcome variables: Black Box maintenance/condition (measured by percent canopy foliage) and Success of Black Box regeneration (measured as successful or unsuccessful). The spatial area of interest was four irrigation districts on the NSW Murray floodplain.

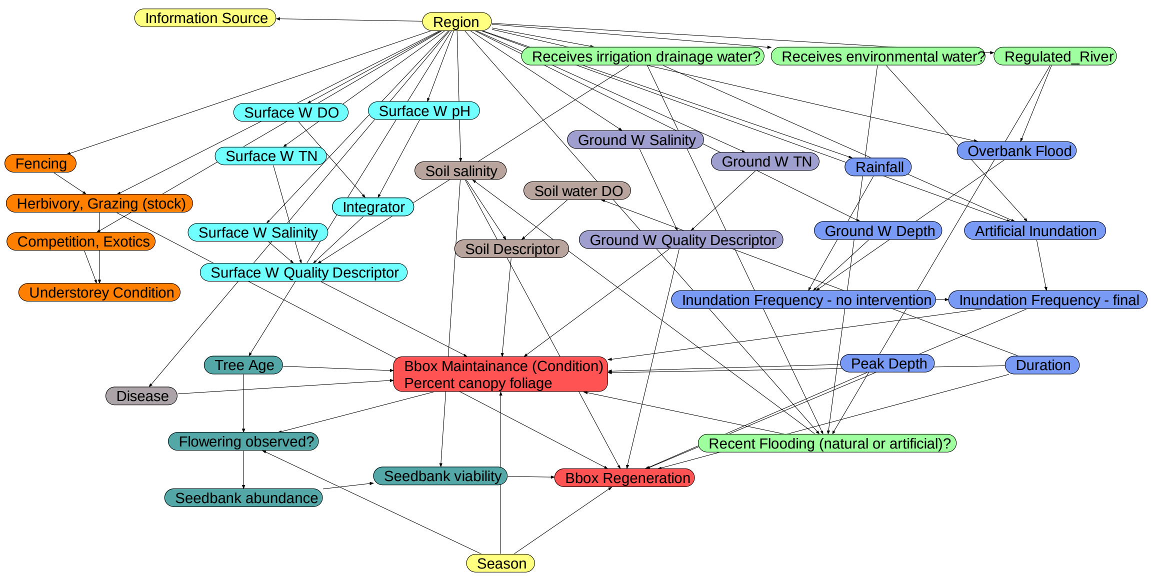

Figure 2. Bayesian network structure for Black box (*E. largiflorens*). Colours indicate different system components (orange: landholder management; light blue: water quality; brown: soil quality, purple: groundwater quality; dark blue: inundation - ground and surface water; green: water management; teal: indicators of tree health; red: outcomes; yellow: spatial and data source variables).

Building the evidence base

The next step in the cycle was to build the evidence-base. Model parameterisation methods are described elsewhere (Pollino et al. 2007b).

Given the paucity of data relevant across the NSW Murray region, the model incorporates data and knowledge from other areas within New South Wales (Murrumbidgee and Chowilla floodplain) and from South Australia (Chowilla floodplain). Monitoring and research studies had taken place in these areas measuring the response of Black Box communities to different wetting cycles, and access to alternative surface, ground and soil water sources. Information on soil and water quality information and grazing practices came from a range of sources, including reports published papers, and regional observations.

As model inputs came from a variety of sources, the Bayesian network can be used to represent inputs independently, where predictions are based on inputs from each of the data providers, or as integrated inputs across data providers, using the method described in (Pollino et al. 2007a). For a full description of the model and data sources, see (Pollino and Hart 2005). To represent spatial variability in physical and chemical conditions across the Murray floodplain, specific variables were specified as being site dependent. The model outcomes can be represented based on a defined spatial area or across all spatial regions. Regardless of the input information and spatial scale, the model outcomes were consistent, as discussed further below.

From complexity to simplicity

Bayesian networks are particularly useful for integrating evidence to better understand complex systems (Pollino et al. 2007a). Although there are virtually no limits to the complexity of Bayesian models, complex models are not always warranted for analysing NRM issues. Using sensitivity analysis (Pollino et al. 2007b), we can assess complex models to determine the key variables influencing outcomes.

In the complex model (Figure 2), sensitivity analysis consistently showed that regardless of where the data was collected or who collected it, an altered wetting regime (less than a one-in-five or greater than one-in-ten year cycle) significantly impacts on the condition of Black Box depressions and reduced the success of regeneration events. Grazing pressure was also an important factor in regeneration. By comparison, other factors (soil quality, groundwater quality, surface water quality) only have a minor impact on tree health and regeneration, regardless of the region of interest.

Given the consistent pattern in the evidence, it was decided to reduce the complex model with 38 variables (Figure 2) to a more simple representation of 20 variables (Figure 3). The simple model is composed of the variables that have the greatest influence on the outcome variables.

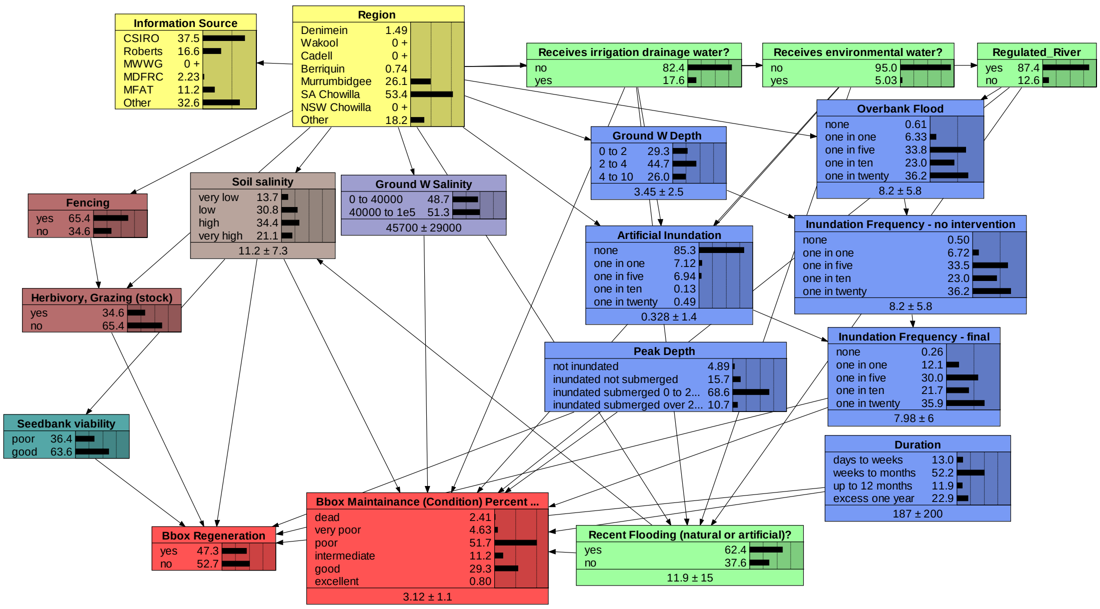

Figure 3. Simple Bayesian network for Black box (*Eucalyptus largiflorens*), showing model states.

Using sensitivity analysis, we found that wetting regime and fencing/grazing impacts were highly influential on model outcomes, and consequently these model components were retained. As it is widely perceived by stakeholders that salinity can also impact on Black Box, the soil salinity and groundwater salinity variables were also retained in the model (full documentation on model evaluation tests is available in (Pollino and Hart 2005)). As this model building exercise was largely stakeholder driven, and the primary use of this model was an education tool on managing Black box depression areas, it was seen as important to keep the salinity variables, despite this decision appearing counterintuitive in the model simplification process.

The model findings reinforced that investments in the wetland watering program were effective in maintaining the health of *E. largiflorens* depression communities. It was clear that the small floodplain wetland communities had become increasingly isolated on the Murray floodplain due to the loss of the natural flow regime and reduced incidence of flooding (although in some cases water was being stored in wetland depression areas and this was also detrimental). As most depression wetlands were also on private lands, grazing activities were also impacting on maintenance and regeneration potential.

By integrating evidence on *E. largiflorens* from across the Murray floodplain, we demonstrated that a watering frequency of between one in five years and one in ten years was optimal in maintaining tree health and promoting regeneration. For the environmental watering program to be successful, this needed to be accompanied by a fencing program. These findings have been reinforced by subsequent studies in the region. Ideally, to complete the NRM cycle, such new findings would be incorporated into the model to fulfill the adaptive learning process.

4. DISCUSSION

Landscape Logic hopes to deliver improved capacity, knowledge and tools to assist in our understanding of biophysical and social drivers for water quality and native vegetation condition, with the view to improving decision-making in NRM. We have used conceptual models to define NRM problems and to target evidence collection. The conceptual model and evidence are being used to construct Bayesian Networks. Currently, we are at the stage of building highly complex Bayesian network models. Through sensitivity analysis and model testing, we aim to achieve a practical but robust level of simplicity, enabling prioritization of investment activities. Ideally, the Landscape Logic models should be updated as investments are implemented and on-ground monitoring of change in resource condition is undertaken. Unfortunately, this iteration back through the NRM investment process is rarely implemented.

The adoption of the Landscape Logic approach can assist regional NRM bodies in grappling with 'wicked' problems and provide a tractable, repeatable and measurable process for demonstrating causality in linking investments to outcomes. As stated in Section 2, we use Bayesian networks to link investments through to outcomes, but this does not preclude other approaches to integration. Regardless of the modelling approach used, examining links between on ground activities and outcomes generally requires long term commitment and ongoing investment, a feature that is sadly lacking in NRM arrangements today.

REFERENCES

ANAO. 1997. Commonwealth Natural Resource Management and Environment Programs, Audit Report No. 36 1996–97. Canberra: The Australian National Audit Office.

ANOA 1998. Preliminary Inquiries into The National Heritage Trust. Audit Report No. 42, Australian National Audit Office: Canberra

ANAO 2001. Performance Information on Commonwealth Financial Assistance under the Natural Heritage Trust. Audit Report No.43, Australian National Audit Office: Canberra.

ANOA 2008. Regional Delivery Model for the National Heritage Trust and National Plan for Salinity and Water Quality. Audit Report No. 21, Australian National Audit Office: Canberra.

Bellamy JA, Walker DH, McDonald GT, Syme GJ. 2001. A systems approach to the evaluation of natural resource management initiatives. Journal of Environmental Management 63(4):407-423.

Greiner R. 2004. Systems framework for regional-scale integrated modelling and assessment. Mathematics and Computers in Simulation 64(1):41-51.

Hajkowicz S. 2009. The evolution of Australia's natural resource management programs: Towards improved targeting and evaluation of investments. Land Use Policy 26(2):471-478.

Iwasa Y, Andreasen V, Levin SA. 1987. Aggregation in Model Ecosystems. I. Perfect Aggregation. Ecological Modelling 37:287-302.

Nias DJ, Alexander P, Herring M. 2003. Watering private property wetlands in the Murray Valley, New South Wales. Ecological Management and Restoration 4:5-12.

Pollino CA, Hart BT. 2005. Case Study: Murray Irrigation Limited. National Program for Sustainable Irrigation Project: Delivering Sustainability through Risk Management. Clayton, Victoria: Monash University.

Pollino CA, White AK, Hart BT. 2007a. Examination of conflicts and improved strategies for the management of an endangered Eucalypt species using Bayesian networks. Ecological Modelling 201:37 - 59.

Pollino CA, Woodberry O, Nicholson AE, Korb KB, Hart BT. 2007b. Parameterisation and evaluation of a Bayesian network for use in an ecological risk assessment. Environmental Modelling & Software 22:1140-1152.

Rittel, H, and Webber, M (1973) Dilemmas in a General Theory of Planning. Policy Sciences 4:155-169. Elsevier Scientific Publishing Company, Amsterdam.

Simon H. 1955. A Behavioral Model of Rational Choice. Quarterly Journal of Economics 69:99 -118.