Exploring Solutions to Australia's Long-term Land and Water Problems Using Scenario Modelling

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Abstract: The status of Australia's land and water resources in fifty or one hundred years time will be the result of deep-seated and slow-operating biophysical change processes and how fast and how much managers respond to those changes. These changes in our landscapes are widespread and far reaching, and their flow-on effects are likely to be felt throughout the economy and society, not just in the rural and natural resource (NRM) sectors. Much action is being undertaken in response (eg the Prime Minister's National Action Plan for Salinity and Water Quality in Australia), and much research is being done to understand the change processes in order to underpin their management. There are however uncertainties about the extent and rate of the change processes and about how we will choose to respond to them. These uncertainties mean it is impossible to predict what the effects of changes and management will be, but good knowledge of what outcomes are likely (or at least possible) is needed for determining current NRM policy that is to be effective in the long term. We have developed an analytical framework for combining existing knowledge and uncertainties to describe physically-feasible future outcomes. The framework has been developed for the whole economy including the natural resource sectors. The framework (the *Australian Stocks and Flows Framework*) is described elsewhere in these proceedings. Key feature of the modelling approach are that it combines relatively slow and fast operating landscape processes, it gives whole economy outcomes by including material flows and flow-on effects between sectors, and it operates at the whole-continent and 50-100 year scales. This paper describes a range of physically-feasible scenarios representing alternative approaches to dealing with NRM trade-offs and how they can help current policy development.

Keywords: Natural Resource Management; Land; Water; Agriculture; Scenarios

1. INTRODUCTION

Since European settlement the nature and functioning of many landscapes have changed significantly in Australia. The biggest changes have come about from replacing native vegetation with crops and pasture, grazing native grasslands, diverting rivers and streams for irrigation. On the one hand, the changes have been highly productive economically and socially for Australia. However, we are increasingly becoming aware of some of the negative changes that have occurred and the environmental, social and economic costs that they bear. The National Land and Water Resources Audit[1] is reporting on many of these issues.

The challenge facing our policy makers, natural resource managers and the community is to manage Australian landscapes to minimise the costs and maximise the benefits. A number of significant factors confound that task. Many of the biophysical processes that are at the core of some of our landscape problems are slow moving and operate over large spatial areas. For example, soil acidification frequently only begins to affect production after decades of dropping pH, and while surface pH may be controlled with liming, subsurface acidification may continue, ultimately affecting plant production, polluting groundwater and waterways. Many of the impacts of landscape change on, for example, biodiversity, soils, groundwater, streams, wetlands, roads and buildings are spatial and/or temporal distant from the original causes.

Multiple objectives, frequently also at different scales, make landscape management and policy development difficult, and can lead to conflict between different stakeholders. The increasing of flows in the Snowy River is a recent high profile example.

[1] www.nlwra.gov.au

Understanding the diversity of causes and drivers of landscape change is an important step in developing policy for managing our landscapes. Drivers of landscape change can be slow (eg climate change) or relatively fast (commodity prices); they can originate from within our landscapes (altered hydrology) or externally to them (mad cow disease); and they can be physical, economic or societal.

In Australia we do have much good knowledge and research about the operation and effects of many of the drivers of landscape change. However there are also many uncertainties: there are gaps in data and understanding of some processes, and there are some drivers that will always be uncertain in their behaviour. This uncertainty renders prediction about many aspects of our future landscapes impossible.

In summary landscape and natural resource policy makers are faced with processes operating at multiple temporal and spatial scales, multiple objectives, patchy data and inherent uncertainty. This is particularly the case for long-term and state or national scale policy. This paper discusses a scenario planning technique and scenario modelling tool that have been designed to help policy makers deal with some of these issues. An analysis of future water use in Australia is used to illustrate the method.

2. LANDSCAPE SCENARIOS

In the 1970's the Royal Dutch Shell Company pioneered a scenario planning methodology for helping in the development of strategic policy [Schwartz, 1997]. The technique is based around developing a small number of scenarios centred around sets of critical uncertainties. Typically the scenarios are described qualitatively with minimal analytical input. We have combined this methodology with simulation modelling using the Australian Stocks and Flows Framework (ASFF) to develop scenarios for Australian landscapes. This revised method retains the ability to deal with critical uncertainties but uses a high level of analytical and predictive information. In the original scenario planning methodology a key feature is the *process* of developing the scenarios that is undertaken by the owners of the issues. The process involves learning and understanding and can be more important than the final scenarios. This aspect is retained in our modified method, through the interactive manner in which scenarios are developed in ASFF. The general method is described below and the modelling framework is described in the following section.

The key steps in the scenario planning method are:
1. Identify the focal issue. This step needs to be reasonably specific to help shape the choice of scenarios and to help evaluate the implications of the scenarios.
2. Brainstorm the driving forces of the future. This identifies the variables that need to be accounted for in some way in the scenarios. This step is creative and should be involve sharing of data and understanding.
3. Identify the key predetermined variables – those drivers that are important in shaping the future and are reasonably predictable. These drivers will be in common to each scenario that is developed.
4. Identify the critical uncertainties – those drivers that could have a fundamental influence on the future but whose likely trajectories are unknown.
5. Design the scenario logic based on the critical uncertainties. Each scenario can be defined by the action of a number of different critical uncertainties. The drivers defining a scenario do not have to be naturally aligned however they should form a coherent scenario without disjunctions and internal contradictions and they should be relevant to the focal issues. Experience suggests that two to four scenarios is a good number to develop. The scenarios should be challenging but they should also be plausible to a critical mass of stakeholders. They should also be recognisable from the trends of today.
6. Model the scenarios. The preceding step is highly creative – in this step that creativity is complemented by physical realities that are embodied in data. In this stage the scenarios become more concrete as the time courses of key physical parameters are defined in the modelling framework. Additional information not included in the model can also be used to give further context and detail to the scenarios, as long as it is quantitatively consistent with the modelled variables. The modelling processes in ASFF is highly interactive and can be conducted in small groups with stakeholders playing an active role. Adjustment to the original model logic may be needed as constraints and trade-offs are revealed. This is an important part of the active-learning goal of scenario planning.

Scenarios can take various styles depending on the predictability of key variables, the role of controllable and uncontrollable drivers, and the purpose of the exercise. Three typical uses of scenarios are: for choosing between alternative futures (Which of theses scenarios do we want to make happen?); for wind-tunnel testing strategy (Is our strategy robust to these different possible futures?); and, to help predicting (What factors might give early indication that one or other of these scenarios is going to unfold?). High profile examples of these three different uses of scenarios include, repectively: choosing between alternative landscape futures in the Netherlands; developing robust economic strategy for Singapore in an unstable Asia; and, Shell gaining market advantage through the oil price fluctuations of the 1970's and 1980's [O'Brien, 2000]. We have developed some scenarios of the choose-an-alternative variety: examining the long-term effects of three different regimes of retiring agricultural land and planting perennial vegetation [Dunlop et al., 2000]; and examining the long-term effects of three different population levels [Foran and Poldy, 2001].

While any one set of scenarios could have a mixture of styles, understanding these different uses and the roles of different types of variables can resolve much of the confusion that sometimes surrounds the use of scenarios.

Given the number of critically uncertain drivers affecting Australia's future, the most useful natural resource scenarios are likely to be based around a mixture of uncontrollable or unknowable drivers and policy/management responses to those drivers. Such scenarios may have elements of choosing between alternatives and wind tunnel testing styles. We have developed scenarios of this type for water use in Australia, see below [Dunlop et al., 2001]; and Australian fisheries, where there are significant uncertainties concerning some fundamental biological parameters as well as choices to be made about future fishing effort [Lowe et al., 2001]. Such scenarios can be used to give context to the development of robust strategy and policy by providing detailed descriptions of a likely range of possible futures.

3. THE AUSTRALIAN STOCKS AND FLOWS FRAMEWORK

The Australian Stocks and Flows Framework is a model of the Australian physical economy in the *whatif* modelling platform. Turner et al. [2001] provides a detailed description of the modelling framework elsewhere in these proceedings. Some of the key features of ASFF, and its treatment of land and water, are described below.

- ASFF has about 30 modules covering *all sectors* of the physical economy;
- it keeps track of stocks, flows and transformations of *physical things* (eg, people, cars, buildings, building materials, food); and
- it includes a *historical grounding* period of 50 year for most sectors and 150 years for agricultural land, and a 100 year *simulation* period.
- The framework is a large ***structured*** set of multi-dimensional ***databases*** that are connected by conceptually simple equations representing the *physical processes* of the economy.
- The level of *spatial disaggregation* in the model varies between sectors, the most disaggregate sectors are agriculture (58 statistical divisions) and water resources (74 water regions).
- It operates on a *5 year time step*, thus avoiding much variation due to weather and economic cycles that could not be accurately predicted or input to the model over the simulation period.
- ASFF is *not an optimisation* model, the *user* must play a very active role iteratively constructing and exploring alternative scenarios – *learning* about the behaviour of the economy.

There are two distinct modelling phases in using ASFF: calibration of the history and simulation modelling of the scenarios. The calibration uses the structural relationships between data items in the framework, whatever actual historic data is available, expert knowledge and theory. The process fills any data gaps and resolves any inconsistencies creating a complete and consistent data set for the historic period. This process provides the quantitative starting point for scenarios in terms of both the physical state of the economy (how much stuff there is) and the processes of the economy (how all the stuff relates to each other). The scenario modelling phase consists of specifying various input parameters, guided by the present-time values and trends that were derived from the history period.

Modelling in both the calibrator and simulator is interactive using a graphic interface. As the simulation model is not systems-dynamic the modeller may have to iteratively adjust input parameters to close feedback loops that are left open in the model structure. This is a highly transparent process and is a particular feature of this type of modelling that promotes active learning about the system being simulated.

3.1 Land and Agriculture in ASFF

The agricultural module in ASFF deals with cropping and grazing land, land degradation, fertiliser and irrigation inputs to agriculture, crop and animal production, and energy and labour requirements.

To illustrate the style of modelling the logic of the cropping routine is described below (Figure 1).

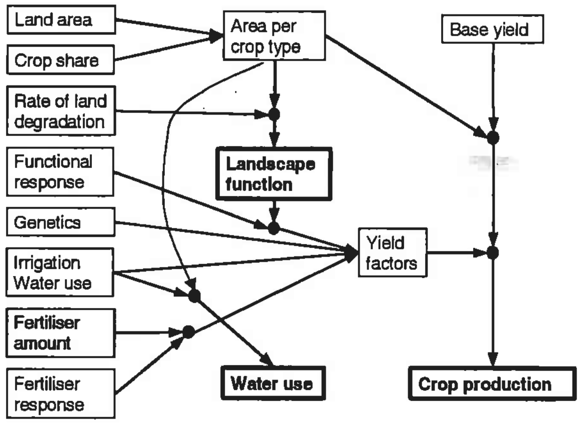

Figure 1. Schematic diagram of the logic of agricultural land use and crop production in the Australian Stocks and Flows Framework. Bold boxes indicate key output variables.

- The total area of crops and sown pastures in each statistical division is derived from the historic area plus additions and minus deletions from the agricultural estate;
- the land is apportioned to irrigated or dryland agriculture;
- the mixture different crops and pasture in each statistical division is specified ("crop share" in Figure 1); and
- area of each cropping activity is calculated.
- Landscape function evolves incrementally as a function of the area of each crop type and a rate of degradation for each crop type (see section below).
- The volume of each commodity produced in each statistical division is determined form a base yield and the area of each crop. This is then increased and/or decreased by yield factors representing the effects of loss of landscape function, genetic improvements, irrigation and fertiliser.
- Irrigation water use is calculated as the product of the area of each irrigated crop and a respective water use intensity.

Animal feeding and production, and agricultural energy, labour and fertiliser use are modelled at a similar level. The landscape function procedure is one of the more complex in the model and is described below.

3.2 Landscape Function in ASFF

The framework calculates four landscape function parameters: soil acidity, soil structural decline, dryland salinity and irrigation salinity. A mismatch between management and the intensity of production is modelled as an incremental increase in one or more of the landscape function parameters.

Central to the landscape function procedure is the concept of vintaging. In the framework the area of cleared land that is added to the crop and pasture estate prior to 1901 and in each five year period since is accounted at the statistical division level. Each age class is referred to as a vintage. In a given time period land can only be added to the current vintage, but land can be retired from any vintage. Landscape function is calculated for each vintage in each statistical division, hence each region can have a distribution of landscape function.

In each time period, for each vintage, an incremental change in each landscape function parameter is calculated as a function of the area of each cropping activity in the statistical division. The rate of change per hectare of crop activity varies among regions and crop types, and can vary over time to reflect more or less sustainable management practices. The area of cropland affected by moderate dryland salinity in Australia in three scenarios is illustrated in Figure 2. These scenarios differ in the areas of cropland converted to perennial vegetation and the concomitant reductions in the rates of dryland salinity [Dunlop et al., 2000]. Decreases in the areas affected reflect degraded cropland being retired, not reductions in dryland salinity.

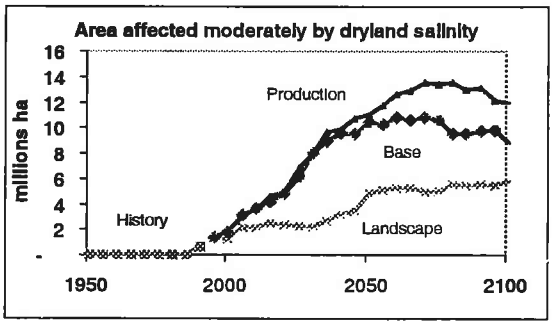

Figure 2. The area of cropland affected by moderate or worse level of dryland salinity in three scenarios[2]. See text for explanation.

The relationships between each of the four parameters of landscape function and crop and pasture yield are specified by functional response curves. The four yield responses are combined to give a single landscape function yield response that indicates the degree to which yields are decreased by land degradation, Figure 3.

[2] These results will change when ASFF is up-dated with recent and pending NLWRA data.

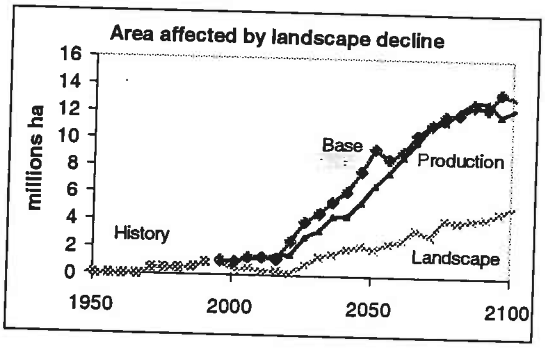

Figure 3. The area of cropland where yield is decreased by at least 50% due to a combination of soil acidification, dryland salinity, irrigation salinity and soil structural decline in three scenarios[2]. See text for explanation.

3.3 Water in ASFF

Water use is calculated separately for all sectors of the economy based on the level of activity and a specified water use per unit of activity, as illustrated for cropping in Figure 1. In the water resources module of ASFF water use from the different sectors is consolidated, and water resources and diversions are modelled. If, during the modelling process, water use in a region exceeds supply then a "tension" occurs that the users may choose to resolve. They could decrease the amount of water using activity (eg area irrigated) or the water use intensity (volume per hectare), transfer water from another region, or possibly overdraw groundwater supplies. This is an example of the active role of the user during scenario development.

4. THREE WATER SCENARIOS

In Australia about 75% of diverted water is used on irrigated crops and pastures and about 20% for industrial and urban uses [NLWRA, 2001]. About 80% or 19,000 GL of the diverted water is taken from surface water. While in total this is less that 5% of Australia's total surface water run-off, in many regions, like the Murray Darling Basin, diversion is as high as 80% of the surface water resource. Australia has plenty of water but our use patterns do not reflect the distribution of the resource, and past trends in water use are not sustainable. There is also a significant range in the value of agricultural product per litre of water used to produce it. And industrial and urban uses, although small in volume, will always out-compete agricultural uses if a market exists.

We recently undertook a study on Australian water futures using some of the methods described in this paper. The study produced a series four reports which are available on the internet[3].

To explore the important issues and drivers of change of water use in Australia we held a one-day workshop with participants from the state and federal agencies responsible for water resources, a broad range of irrigation industries and the urban water sector. The workshop focussed on the major determinates of water use in each industry and state and how they likely are to change in the next 50 years.

Prior to the workshop two draft reports were prepared providing: overviews of the water industry, water use and water issues in Australian and in each state, and an analysis of water use and resource statistics for each statistical division. These draft reports were distributed to the workshop participants as background material, and they were revised following the workshop.

The workshop was structured to give everyone several opportunities to contribute and allowed for plenty of free flowing discussion and debate. Our notes from the workshop were collated, the major drivers of water use were identified and categorised as *givens* or *critical uncertainties*, and four draft scenarios we briefly sketched out based on the critical uncertainties. These drivers are abbreviated below in Table 1. The notes, drivers and scenarios were distributed to the workshop participants and a wider group of experts for comment. Following feed-back two of the scenarios were combined. The revised document is the third report in the series.

Table 1. Abridged list of given and critically uncertain drivers affecting future water use in Australia.

Givens
• Some increase in irrigation in north Australia
• Some contraction of lower value irrigation
• Significant expansion of higher value uses
• Some increase in environmental flows in south
Critical uncertainties
• Large expansion of irrigation in the north
• Boom in live beef exports and feed-lots
• Boom in exports of horticulture
• Big expansion of plantation forestry significantly reduces catchment water yields
• Climate change driven decrease in rainfall AND increase in water demand
• Increase in urban water use per capita
• Water transferred from irrigation to urban uses
• Societal demand for environmental flows

[3] www.dwe.csiro.au/research/futures/publications

The scenarios were modelled using ASFF and some spreadsheet modelling. The scenarios were: Commodity J-curve, Urban extravagance and Climate change double whammy [Dunlop et al., 2001]. Each scenario consisted of one or more strong external drivers and some adaptation in the water using sectors.

The Commodity J-curve scenario was driven by increases in world demand for Australian live beef and horticulture. The adaptations were: a major increase in irrigation in northern Australia with water use in the north exceeding that in the south by 2050, and in southern Australia a shift from irrigated pasture and rice to higher value crops with a net 25% decrease in water use giving rise to significant increases in environmental flows.

The Urban extravagance scenario was driven by: high population growth (32 million by 2050) and increasing per capita water use (20% by 2050) leading to significant increase in demand for water in the cities, and increasing urban environmentalism demanding plantation forestry and increases in environmental flows. The adaptations were: in southern Australia significant reductions (36% by 2050) in the area of irrigated pasture, rice and cotton freeing up 3,800 GL, with 2,000 GL being diverted to urban uses, and increases in plantation forestry in high rainfall areas leading to reductions in catchment water yields of 1,000 GL, leaving only about 20% of the original saving of irrigation water to increase environmental flows.

The Climate change double whammy scenario was driven by: increased demand for water by people, crops, pasture and forests (20-30% by 2050), combined with lower rainfall leading to major constraints to water availability in southern Australia. The adaptations were: major reductions in irrigated pasture, rice and cotton (50% by 2050) in southern Australia which yielded just enough water for increased urban uses and to maintain current environmental flows in the most stressed systems only.

In each of these three scenarios the adaptations were the key to maximising the benefits and minimising the disadvantages. Failure to adapt would incur significant cost in terms of lost opportunities and/or increased social, economic and environmental impacts. The scale of the adaptations needed in each these scenarios has significant implications for infrastructure investment, investment in agriculture and NRM, and broader rural and regional development. Furthermore, the implications vary considerably between scenarios and regions [Dunlop et al., 2001].

5. CONCLUSIONS

The future of Australian landscapes will be driven by many different forces, some of which are hard to quantify or intrinsically unpredictable. A combination of scenario planning and national-scale, long-term simulation modelling can provide context and data at the appropriate scales to reveal insights into the future that have significant implications for high-level, national and state scale policy development and investment.

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