Unique Mapping Areas as the basis for Integrating Biophysical and Economic Modelling in the Liverpool Plains

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Options for managing dryland salinity must be evaluated in the context of both their effect on the biophysical processes driving salinisation at the catchment scale and their economic viability at the farm scale. This requires models which link effects at these different scales, as well as integrating biophysical and socioeconomic factors. A conceptual catchment model of the economics of dryland salinisation incorporating biophysical constraints and feedbacks has been developed by Greiner (1994), based on the use of model farms representative of various regions of the catchment. This paper examines the basis for delineating biophysically homogeneous landscape units ("unique mapping areas" or UMAs) as a framework for modelling, research and extension within the catchment.

1. INTRODUCTION

Soil salinisation associated with rising groundwater is of increasing concern in the Liverpool Plains catchment in northern NSW. A hydrogeological investigation of the area by Broughton (1994a, b, 1995) indicated that 195,000 ha of land in the catchment has watertables within 5 m of the surface and 30,000 ha within 2 metres, causing soil salinisation and a decline in crop and pasture production. A major multidisciplinary program is underway to identify land management strategies for the catchment which are sustainable both economically and ecologically. The project is a part of the National Dryland Salinity Program jointly funded by the Land and Water Resources Research and Development Corporation and the Murray Darling Basin Commission, and involves a consortium of state and federal agencies and local community groups.

The main focus of the project is to develop and integrate models of the physical processes controlling salinisation and the economic and social environments which determine how management and mitigation strategies are adopted. The processes driving salinisation are complex, operate at the catchment scale and involve both time lags and spatial effects, so that increased recharge in one area manifests as salinisation in discharge areas further down catchment and at a later date.

The challenge for the local community is to identify and implement land management strategies for the catchment as a whole which address the problems of salinisation and are economically viable. Assessment of land management options requires the use of models which integrate biophysical and economic effects, and account for the spatial linkages and time lags inherent in salinisation processes.

For the purposes of such research, it is advantageous to explicitly define the informal "land use units" which underlie management in the catchment. These units have a biophysical basis (the constraints to land use imposed by soil, topography, climate and hydrogeological processes driving salinisation) and an economic expression in terms of productivity, forming a natural link between the two disciplines. Since land use changes, it is preferable to define the units directly in relation to their biophysical attributes, as unique mapping areas or UMAs.

2. INTEGRATING BIOPHYSICS INTO AN ECONOMIC MODEL OF DRYLAND SALINITY

Greiner (1994) developed a conceptual model to investigate the economics of dryland salinity which aimed to "integrate land use-variables, hydrological conditions and economic and financial constraints within a single farm framework in order to account for the farm-level decision making basis of this catchment-scale land degradation problem". Based on this farm-level model, a catchment-scale spatial equilibrium modelling exercise is underway (Greiner and Hall 1995).

The model aims to define optimum land use strategies for the catchment as a whole over the long term by maximising present value of the total incomes from farming over the entire basin, taking into account the status of the natural resource base. It requires division of the catchment into regions with distinctive biophysical and land use characteristics for which hydrogeological linkages can be described and quantified - that is, into UMAs.

The main focus of the model is on catchment scale strategies and policies, acknowledging that land use in some parts of the catchment may affect the productivity of other regions. Despite its explicit farm cash flow analysis, it is not primarily a farm management model. Rather, it explores which land management strategies are optimal in different areas of the catchment. It provides a basis for assessing their implications for resource sustainability and the financial viability of model farms which capture the prevailing agricultural production structures in these areas.

Three sets of biophysical constraints are integrated into the catchment model: climate, soils and hydrogeology. Topography is not considered explicitly, but its effect is implicit in determining land use options which are constrained by slope.

Climatic variability is important in determining seasonal productivity and groundwater recharge, and is introduced into the model using discrete stochastic programming (Cocks 1968). Long-term seasonal climate records are used to define "average", "dry" and "wet" conditions for summer and winter and to allocate frequencies to these season types. Soil type is the other major factor which affects crop productivity and recharge. The links between rainfall and crop yield, and rainfall and recharge for different soil types can be quantified using computer simulation models of crop / soil / water interactions such as PERFECT (Littleboy *et al* 1989) or APSIM (Keating, 1995).

Hydrological processes related to salinity are integrated into the economic calculations by considering:

- the groundwater level beneath each model farm at the beginning of the optimisation period relative to the critical waterlevel for onset of salinisation, assumed to be 2 metres (the threat of salinisation). This is a function of location within the catchment relative to the major aquifers.
- the change in groundwater level as a result of recharge (deep percolation) within the farm. Recharge is a function of annual rainfall and evapotranspiration, soil type, topography and land use (which determines water use by vegetation cover). On-farm recharge can be modified by land management practices and so is an internal economic effect.
- the change in groundwater level due to lateral flow and upward leakage from pressurised aquifers. This is a result of catchment scale flows and processes, is independent of land use in the immediate vicinty and varies significantly across the catchment. Aquifer transmission can be considered as the "carrier" of external costs between regions. Importantly for the catchment model, these linkages must be quantified spatially and temporally.
- the salinity encroachment rate, or rate at which land becomes salt affected as the water table rises above the critical level. This depends on topography, soil type and hydrogeological linkages, but is poorly defined at present.

3. UNIQUE MAPPING AREAS

The catchment model thus imposes a number of requirements for the UMAs, as follows:

- they must be coherent in terms of land use and productivity since they form the basis for the analysis of the economics of the model farms. This assumes a dependence on soil type, topography and climate, the primary limiting factors in determining land use options.
- they must be coherent in terms of the hydrological parameters described above (depth to groundwater, rates of recharge, leakage from the upper aquifer, salinity encroachment rate)
- it must be possible to quantify the hydrological connections between the units. This requires knowledge of the spatial patterns of pressure distribution and flow between the major aquifers. The requirement for hydrological connectivity of the units means that they must be defined spatially within the catchment.

While the initial purpose of defining UMAs is for catchment modelling, the units are equally important in transferring the results of the modelling to the community since they can provide a framework for discussion of land use policy for the whole catchment. It is thus important that UMAs should relate logically to the types of landscape descriptions used locally in farm planning and landcare activities, including broad commonly recognised land systems such as those formalised by Duggin (in Sim and Urwin 1984 and unpublished maps) and the soil landscape mapping concept used by soil surveyors (see Banks 1995).

The spatial scale and level of categorisation must satisfy the competing demands of economic modelling (small number, low resolution) and biophysical research (high number, high resolution). A suitable scale and level of caterogisation depends on the use which will be made of the units. The ideal situation would be a nested hierachy of UMAs, with regional UMAs (defined at say 1:250,000 for a catchment the size of the Liverpool Plains) for use at the catchment level, which can be split into smaller units if required on the basis of more detailed information. The catchment equilibrium model uses a grid structure with a cell size of 5 x 5 km (that is, areas less than 25 km^2 will not be distinguished). Such a broad categorisation is obviously unsuitable for many other purposes and the provisional UMAs described below are in many cases an aggregation of smaller units.

Considerable effort has gone into developing methodologies for landscape classification and description. The most widely accepted in Australia is the land systems approach (see for example, Christian and Stewart, 1968; Speight 1988). This study differs from the land systems approach only in that it requires an explicit description and quantification of the hydrological connections between the units.

The question arises as to whether definition of specific land units is really necessary in the light of modern GIS techniques which can store and analyse spatial data on a range of characteristics as required. In general, for biophysical modelling it is important to maintain as much information on spatial variability as possible since many physical characteristics vary independently. In this case, the economic model is sufficiently complex that it is not technically feasible to handle the extra dimensionality which would result from considering all possible combinations of physical characteristics. In addition, confidentiality constraints in using farm financial statistics require that the data be aggregated. Delineation of broad regions is likely to be useful in discussing policy options and providing consistency in transferring the results of the modelling and other research to the community.

4. DATASETS AND PREVIOUS STUDIES

The essential criteria to be considered in defining UMAs are those which constrain land use options (soil type, topography, climate) and the hydrogeological characteristics which control salinisation (groundwater level, recharge and pressurisation of the upper aquifer). Primary datasets available at catchment scale relating to these characteristics include:

- Geological mapping at 1:250,000 (NSW Department of Mineral Resources)
- 1:250,000 topographic data (AUSLIG)
- Hydrogeological mapping at 1:250,000, including areas with watertable within 5 m of the surface (NSW Land and Water Conservation: Broughton 1995)
- Lands with slope < 2%, gazetted as floodplains under Part 8 of the Water Act (NSW Land and Water Conservation)
- Climate surfaces with 2.5 km gridcell, derived from ESOCLIM (Hutchinson 1989).

There is no complete soil map for the catchment, although Duggin (in Sim and Urwin 1984) provides a description of major soil types by great soil group within each mapped land system (see below). Soil landscape mapping of the catchment is underway, and the Curlewis 1:100,000 map has been published (Banks, 1995). Information on soil type is essential both to determine land use options and to estimate recharge under various land uses. Major soil types for each UMA will be derived from the land systems mapping, the available soil landscape mapping and soil data from observations at over 700 points throughout the catchment (Banks 1995 and unpublished data).

Previous studies and common usage provide four systems of land description for the catchment, each defined for different purposes and based on different criteria, as follows:

- Broughton (1995) divided the catchment into six hydrogeological provinces on the basis of the dominant aquifer system and other hydrogeological characteristics, at 1:250,000.
- Duggin (in Sim and Urwin 1984, and unpublished maps) describes 17 land systems for the catchment based on landform and lithology. The map was published at about 1:330,000 but unpublished base maps are available at 1:25,000 to 1:50,000.

- Soil landscape units have been mapped and described for about half the catchment at a scale of 1:100,000 (Banks 1995 and unpublished data). Banks defines a total of 37 soil landscapes for the Curlewis sheet.

- Accepted practice for land management in the catchment provides a fourth *de facto* set of seven land use units defined in terms of dominant soil type and slope (Donaldson, pers. comm.; Schroder, 1993) - see Table 1.

In addition, Greiner (1994) defined six "model farm" regions for the part of the Liverpool Plains which belongs to the Gunnedah Shire using cluster analysis of farm area and land use data for 377 farms in the region. This description has no explicit spatial dimension (although the clusters can be related to catchment regions in broad terms).

None of these schema fulfils the requirements for the catchment model, but aspects of all of them are important. Only the hydrogeological provinces explicitly define hydrological connections between units, but these do not take account of other limitations to land use options. Duggin's land systems map is relevant in many ways, particularly as it provides the only catchment-wide description of soil types. However, it takes no account of hydrogeological characteristics: for example, the Jurassic and Triassic sediments form a single group, but hydrologically these are three distinct aquifers with differing salinities and flow characteristics. In addition, the boundaries of the alluvial plains are delineated at about 1% slope, excluding a substantial area now gazetted as floodprone lands (< 2% slope). Soil landscape mapping provides the most reliable soils information for the catchment, but is at too detailed a level for use in regional scale models and is not yet available for the whole catchment.

5. UMAs FOR THE LIVERPOOL PLAINS

Using a combination of the datasets above, a set of 11 UMAs have been defined for the Liverpool Plains catchment, described in Table 2 and shown in Figure 1.

The definitions are made primarily in terms of lithology, topography and hydrogeology. The units relate closely (although not exactly) to the land systems, and each falls primarily within one hydrogeological units, with the exception of the Quaternary alluvium (UMA 1) which cuts across all six. Each unit can be readily subdivided on the basis of geology and topography. Where available, soil landscape units provide a logical disaggregation for use at the subcatchment to farm level. In the case of UMA 1, there are a number of possible ways to subdivide the unit - for example, using the alluvial land systems identified by Duggin, by hydrogeological province, soil type or depth to watertable. The choice of subunits will depend on the purpose at hand.

Lands with slope greater than 33% are gazetted as protected lands for retention of timber (see Table 1) could be delineated as a separate UMA on the basis of their distinctive land use. However, the areas are small and discontinuous and function hydrologically within larger, geologically defined units. In addition, the fact that comprehensive clearing restrictions have recently been introduced for all native vegetation reduces the distinction between these are other steep lands.

Farm enterprise characteristics for each unit will be assigned from ABS and ABARE farm financial statistics aggregated using a 5 km grid. Donaldson (1995) has identified a range of land use options for the "land use units" described above, and these can be translated for each UMA, taking into account climate constraints.

In the first instance, recharge for each UMA will be estimated using the PERFECT model (Queensland Department of Primary Industries) to calculate water balance relationships for various crop / soil combinations (Abbs, in press). One aspect of the joint research project is to refine these relationships using a combination of long-term field experiments and modelling (CSIRO Division of Soils, NSW Agriculture, NSW Land and Water Conservation). In the longer term, a more realistic representation of the spatial distribution of recharge may require the use of small, less generalised soil units.

Initial estimates of the extent of groundwater rise for each UMA due to lateral flow and leakage from pressurised aquifers will be inferred from the data of Broughton (1995, 1994a, b). Hydrogeological transfer functions between UMAs will be calculated using Darcy's law, assuming linear relationships. A major component of the joint project is to refine these estimates using hydrogeological models. A comparison will be made between hydrogeomorphic modelling methods (Salama, in press) developed by CSIRO Water Resources, and the MIKE SHE model used by NSW Land and Water Conservation.

The initial runs of the economic model will be made using the currently available estimates. A second set of runs of the model will be made when the biophysical parameters have been refined towards the end of the project.

6. DISCUSSION

Unique mapping areas for the Liverpool Plains have been defined using basic biophysical datasets (geology, topography, hydrogeology), and can be described and modelled in terms of land use, climate, productivity and economic returns. Because they are biophysically based, an agreed set of units can provide a framework for

- integration of research relating to land management in different disciplines
- facilitating transfer of data and results between research projects in different disciplines
- generalising and extrapolating research results from points or limited areas.

By developing a nested hierachy of units at different scales, UMAs can be used as an extension tool for relating the results of catchment scale research and policy development to stakeholders working at sub-catchment and farm scale. A hierachy of units reconciles the conflicting demands for rigour for research purposes as opposed to simplicity for economic modelling and policy development.

Because the units are defined using basic biophysical datasets available in most areas, they also provide the basis for a methodology for transferring the results of research in the Liverpool Plains to other areas affected by dryland salinistion.

" Mapping of land units.....seems to be an intuitive, almost compulsive, activity" (Speight 1988).

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Table 1: Land use in the Liverpool Plains catchment

Slope	Soil	Land use
>33%	All soils	Gazetted "Protected Land" for retention of timber, minimal light grazing
10 -33%	All soils	Grazing
2-10%	Cracking clays	Mainly continuous cropping, usually long fallow rotations of summer and winter crops
	Red earths, red-brown earths, other texture contrast soils	Mixed cropping (mostly winter) and grazing
<2 %	Cracking clays (vertisols)	Continuous cropping, usually long fallow rotations, some irrigation
	Red earths, red-brown earths, other texture contrast soils	Mainly continuous cropping (mostly winter cereals), some grazing and lucerne
	Sandy soils	Mainly timbered or grazing with occasional crops.

Table 2: Unique mapping area descriptions (see Figure 1)

	Description	Major hydrogeological province (Broughton 1995)	% area of catchment	Average slope
UMA 1	Quaternary alluvium, slope <2%.	6	39%	< 1%
UMA 2	Liverpool Range basalt hills, slope > 10% or elevation > 900m.	1	6%	20%
UMA 3	Liverpool Range basalt slopes and adjoining colluvial fans, slope 2-10%	1 / 2	8%	5%
UMA 4	Tertiary basalt outliers	5	2%	7%
UMA 5	Jurassic volcanics and intrusives	3	8%	6%
UMA 6	Jurassic sandy sediments	2	11%	4%
UMA7	Triassic Narrabeen sediments (Napperby and Dibgy formations)	2	3%	3%
UMA 8	Triassic and Permian sediments in the north of the catchment	5	9%	9%
UMA 9	Permian basalts and associated alluvium	4	3%	4%
UMA 10	Devonian to Permian sedimentary hills east of Hunter-Mooki thrust, slope > 10%	4	8%	19%
UMA 11	Devonian to Permian sedimentary slopes east of Hunter-Mooki thrust, and adjoining colluvial fans, slope 2-10%	4	4%	5%