Assessing Best-Practice Environmental Management Options at the decision scale: a model for technology choice and policy analysis

Thilak Mallawaarachchi

[1]CRC for Sustainable Sugar Production, James Cook University, Townsville, Australia

---

AARES 2001
46th Annual Conference of the Australian Agricultural and Resource Economics Society
Canberra, Australian Capital Territory
13-15 February 2002

ABSTRACT

Management of environmental externalities of agricultural production has become a necessity to attain sustainable and efficient use of resources. Policies to promote externality mitigation are moving away from command and control toward industry self-management guided through best-practice guidelines and incentive structures. Assessment of such policies thus entails careful examination of options at operational and strategic levels to ensure optimal compliance at least cost. An integrated modelling approach that links activities at a farm and regional scale is outlined in this paper as a tool for technology assessment and policy analysis. Models are developed to address externalities in Australian sugar cane production in a coastal environment, but may be applicable in a wider context in examining ways to enhance greater environmental compliance through best practice management.

Key words: Externalities, sugar industry, land management, economic modelling

1 Introduction

Agriculture, considered traditionally as the engine of growth, is still an important source of food, fibre and employment. However, many agricultural practices that enabled the provision of affordable supplies of food and fibre to a growing population have come under scrutiny during the past two to three decades, due to a growing awareness of potential environmental impacts of intensive agricultural practices. Non-point source pollution resulting from run-off of agricultural chemicals and fertilisers, soil erosion, and saline and acid discharge from agricultural sites are some notable examples. While scientists are striving to develop technologies to minimise such impacts of global agriculture, social policies in many countries now require all industries to demonstrate compliance with emerging environmental standards relating to their operations. An important aspect of such environmental management measures has been the search for Best Practice Environmental Options, which generally represent a compromise between technologies that are economically attractive and environmentally efficient. Achieving this compromise requires the use of assessment approaches to rank technologies based on their technical feasibility, economic viability and social acceptance.

In response to this demand for assessment technologies to aid decisions regarding technology adoption, various 'tools' such as decision support systems (DSS), integrated modelling systems, and analytical paradigms such as multi-criteria analysis have come to prominence over the past decade. The design focus of these systems varies significantly, but generally directed for use as either research or operational management tools at various decision scales. Given the need to identify solutions that meet resource or operational constraints and known technical relationships between inputs and outputs, the primary basis of analysis of these decision tools is either optimisation, based usually on various mathematical programming techniques and causal relationships, or simulation based on associations and linkages.

Widespread availability of affordable computing power has significantly boosted the efficacy of programming techniques to handle complex mathematical relationships that are often required to model decision choice relating to natural resource management, which is directly linked to land management. In particular, diversity in farming conditions, resource endowment, farmer characteristics and the nature of pollution pathways suggest that the search for effective solutions to land management problems requires a holistic approach to evaluation, including the assessment of net economic benefits of alternative technologies at enterprise and regional levels.

It is argued that one way to enhance the efficacy of such modelling applications would be to develop systems that also offer a 'self-learning' environment for the user and the developer. Drawing on a study to develop a framework to assess opportunities to maximise net farm income for Australian cane growers under changing sugar price and environmental compliance requirements, the paper outlines an integrated modelling and information management system, FarmEa$y. The interactive modelling environment has been designed to facilitate **e**nterprise and **r**egional **e**conomic **e**valuation of best practice environmental technologies in farming.

The paper is organised in four sections. Section 2 presents an overview of the best management practice approach; Section 3 presents the conceptual overview of the modelling approach, and identifies the primary linkages and interactions between different components of the complex system that characterises the farm operating environment. This is followed by some insights from land use studies in the Australian Sugar Industry in Section 4. Section 5 concludes the paper, and presents some insights for future developments that will enable the system to be used for farm and regional level performance assessment and policy applications.

2 Strategic environmental management – incentives for best practice[1]

The environmental impacts of the sugar industry depend both on the long and short run production decisions of cane growers. In the short run, production decisions are made and implemented within the constraints of weather conditions, available technologies and incentive regimes reflected in prices and policies. In the long run, investments are made in new technologies enabling improvements in productivity and production capacity. While in the short run, the focus of environmental policy is on the mitigation of harm, the focus must move to prevention as a strategic response over the long run.

As environmental policies pursue higher levels of environmental quality in industry operations, or higher environmental standards over time, reward systems and encouragement can play a significant role in promoting environmental responsibility. Whereas, over the long term, continued achievement of environmental responsibility may require greater emphasis on penalties for 'wrongdoers' and discouragement of non-compliant practices through market-based mechanisms and planning controls. This is just, because industry has had the time to invest on new technologies to overcome constraints for compliance in the interim. Such a policy regime outlined in Young (2000) is comparable to the infant industry argument for tariff protection for emerging industries, applied across many industries in the post-war period. Analogous to tariffs that were granted to infant industries, assistance for promoting environmental responsibility generally includes technical assistance and investment subsidies (Lichtenberg, Strand and Lessley 1993). Moreover, best practice environmental management approaches have emerged as an effective response by industries aiming to maintain a competitive position in the face of advancing environmental policy (Environmental Protection Agency 1995).

[1] This section is drawn from Mallawaarachchi, Rayment, Cook and Grundy (2001)

2.1 Best management practices (BMPs)

2.1.1 Rationale

Best management practices (BMPs) represent a practice or combination of practices currently determined to be effective for preventing harmful impacts of production. BMPs are a means of preventing or reducing the amount of harm or pollution generated by production units by operating within stated management objectives. For example, best Management Practices (BMPs) are those fertiliser, water, crop and land management practices which lead to increased land productivity, greater fertiliser efficiency, minimum loss of inputs and maintenance or increase in crop yield and quality.

BMPs may be regarded as a logical short run alternative, given the informational deficiencies that surround non-point source pollution. However, its emerging emphasis on prevention, rather than control, makes it a more strategic and long-term response to pollution management (Stanley 2000). Moreover, practice of BMP promotes greater environmental performance, and is also regarded as an insurance against future liability for environmental damage, or adhering to duty of care, as required by most environment legislation. In particular, the rationale for BMP is guided by the following advantages of greater environmental performance as summarised in Department of Environmental Protection (1996):

1. As carrying capacity limits of receiving environments are approached or exceeded, possible expansion and in some cases continued operation of industry can be constrained.
2. With urban encroachment towards industrial areas and rising community concerns in relation to environmental quality, improved environmental performance is critical to public acceptance of industry.
3. Poor environmental performance can incur financial liabilities in fines, clean-up costs, compensation payments as well as negative market reaction.
4. There is growing consumer demand for cleaner products made by cleaner technologies; and,
5. contaminant levels in production inputs are increasing as industries use up better quality raw materials, requiring industries to improve pollution control performance to stay within emission [or discharge] requirements.

As a strategic management tool, one of the most important steps in developing BMPs should be the setting of objectives. Objectives must be achievable, relevant to problem being addressed and delineate a resource-dependent context, so that the manager can see that the enterprise can achieve them. Objectives must integrate production and environmental considerations of firms' practice, permit the entrepreneur to make the full use of available resources and capabilities, and encourage seeking innovations to accomplish higher goals. Without this emphasis BMP's will be seen as an approach that does not effectively signal the need for new R&D (Ervin and Schmitz 1996). Objectives must lead to tactical and operational goals, and flow into decisions and actions, whose achievement should advance the attainment of objectives (Forster and Browne 1996). To be successful, the industry must embrace an attitude of proactive and continued improvement, rather than, a reactive approach limited to compliance with changing environmental standards. Such resource-dependent and action-oriented strategies can be successfully linked to incentive mechanisms and reward system to facilitate greater voluntary participation. Development of such mechanisms involves the assessment of new technologies and policy options at relevant scales and decision contexts.

3 FarmEa$y – a tool for enterprise and regional economic evaluation

3.1 Modelling economic and environmental interrelations

Various approaches have been used to model economy-environmental interactions at various scales. Mallawaarachchi and Quiggin (2001) analysed land allocation in the sugar industry at a mill area level using a regional optimisation framework and spatially disaggregated data. While the approach offered a sound basis to guide regional resource allocations, a need to link with farm level analysis to enable enterprise scale decisions was highlighted. Greiner (1999) investigated the viability of salinity management options using linked farm and catchment scale models that integrate representative farm modelling and regional aggregation methods based on biophysical models focused on catchment hydrology and salinity.

Farm-Sector-Economy models developed by the Danish Institute of Agriculture and Fisheries Economics (Walter-Jørgensen 1998) for instance provide a linked modelling system that can be used to analyse the problems of adjustment at different levels, in response to environmental policy changes. However, they found that such a modelling activity is highly demanding in terms of data and resources. Moreover, it may be difficult to adapt such models to new environments because of the need for detailed information often not available and often irrelevant at operational scale. The aim of the model development in this paper is to capture critical factors affecting industry performance at various scales at which decisions are taken to address implementation issues associated with resource management for sustainable production.

3.2 Design principles

The analytical scope of the modelling system includes the following assumptions:

1. *Decision hierarchy* – A region representing climate, soils and infrastructure is taken as a collective determinant of industry location. This allows calibration of models to represent regional attributes that are given to a particular set of growers in a mill area.

2. *Efficiency* – Farms are organised within regional constraints and opportunities to maximise perceived benefits. This assumption permits the use of optimisation tools to derive solutions that maximise a given objective function.
3. *Heterogeneity* – Individual farm enterprises are considered different with respect to resource quality. This permits the use of GIS analysis as an aid to model heterogeneity, and to seek similarities to allow integration of like attributes.
4. *Universality* – Move away from representative farm models as farms are considered too diverse, and to encourage ownership of analysis based on 'real data'.
5. *Anonymity* – Emphasis on maintaining anonymity, yet allowing useful comparisons based on aggregations reflecting like attributes.

3.3 Analytical framework

Widespread availability of affordable computing power has significantly increased the use of models as decision aids. Models representing complex linkages and interactions between economic, biophysical and social factors affecting farm performance can now be developed to address various farm management issues. As farm profitability and the effects of farm practices on the environment can vary widely because of farming conditions, resource availability, and farming objectives, etc., finding solutions to land management problems requires a full appreciation of all aspects of farming. Farm models that address these issues can provide a more holistic assessment of farm performance under different conditions, including the full economic benefits of adopting alternative technologies, at both farm enterprise and regional levels.

Mathematical programming is widely used as a tool for farm planning and economic analysis. However, the use of programming models to adoption decisions have met with scepticism because of the high-level expertise needed to formulate and maintain models. Moreover, problems of data availability and difficulties in modifying models with new data restrict frequent and repeated application by the non-specialist. While collaborative research activities and development of regional data systems have helped addressing some of these limitations, our experience in developing such systems suggest that the application of these systems is still largely limited to research uses. Much need to be done to promote their use, for instance, at the farm level.

We outline below an integrated modelling and information management system, FarmEa$y, which addresses some of the above stated limitations and provides an interactive environment to facilitate enterprise and regional economic evaluation of best practice environmental technologies in farming. The basic architecture of the modelling system follows a modular approach to mathematical programming using GAMS, and an interactive Visual Basic interface that handles multiple models and their inputs and outputs. We have used FarmEa$y to demonstrate its potential application to assess the profitability of adopting different management options at a farm scale in collaboration with the industry. Collective implications of farm scale activities for a mill area or a catchment/sub-catchment scale can be assessed using the regional analysis capability being implemented.

3.4 Research Methods

3.4.1 Integrated Research Approach

The work is based on a broader research approach developed at the CRC Sugar to determine economic trade-offs in alternatives land management options involving conservation and development. This approach, presented as Strategic Regional Resource Assessment (SRRA) follows a participatory research process to gather information to examine quantitative economic trade-offs in alternative land uses.

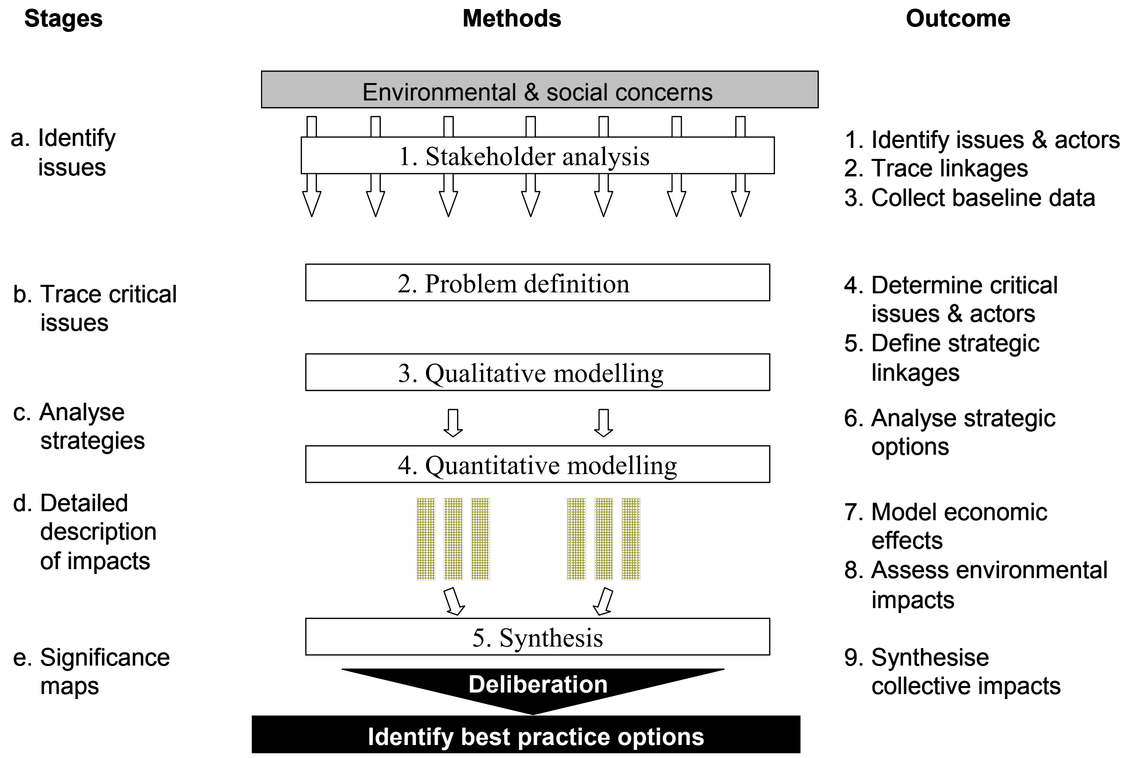


Figure 1: SRRA procedure

The regional allocation model CLAM (Cane Land Allocation Model) determines the net economic trade-offs using information on resource quality, social preferences and market benefits of land use. For instance, spatially referenced resource data using Geographic Information Systems (GIS) analysis; preference based community values for environmental attributes (such as woodlands and wetlands) estimated through Choice Modelling; and market data on traded goods from land uses (such as sugar from sugar cane, and for beef production). Detailed information on CLAM is given in Mallawaarachchi and Quiggin (2001).

While the CLAM model offered a robust means to examine regional level trade-offs, its regional focus made it unsuitable to examine farm enterprise level trade-offs, which are of interest to the Sugar Industry and the community. Study therefore recommended the use of "[m]odels that include fixed costs, personal taxation constraints and private profit objective functions" to analyse important microeconomic effects at an operational level (Mallawaarachchi and Quiggin 2001).

Moreover, the regional outcomes of land use on both economic variables such as income and employment, and on environmental outcomes such as pollution mitigation are linked to farm level decisions. Therefore an integrated approach that links activities at the two levels to assist in enterprise and regional economic evaluation is required to undertake more comprehensive assessment of best practice environmental management options for land use. The following integrated assessment framework incorporates the key concepts of SRRA and the SOHO framework of Kay et al (1999) to form a more informative adaptation. It permits a simple illustration of a rigorous analytical framework, which also links to policy outcomes representing institutional arrangements for ecosystem management.

3.5 Integrated Assessment Framework

This development was guided by two primary objectives:

1. to assess opportunities to maximise net farm income for cane growers under changing sugar prices and environmental compliance requirements; and
2. to conduct farm and regional level analysis to develop policy insights for achieving best practice management options to mitigate harmful environmental externalities in cane farming, based on existing data.

In view of promoting compliance and greater participation, we view externalities as reflections of existing regulatory and incentive structures that deliver a set of goods and services in a particular combination, involving desired and undesired attributes (Cornes and Sandler 1996, Randall 1999). Mitigation of the externality therefore entails examining alternative arrangements for delivering goods and services in a manner most acceptable to all stakeholders (Mallawaarachchi et al. 2001).

The basic features of the framework are illustrated in Figure 2. The basic inputs to analysis are sourced from (a) existing bio-physical data on resource condition, infrastructure and climate variables organised in a GIS, and (b) socio-economic and management information gathered through consultation with the key stakeholders. In the light of researchers gathered knowledge on existing policies and institutions, this information provides the basis for analysing the current context at the farm household and regional scale. A systems analysis perspective is taken to understand linkages between the two scales, including the assessment of critical issues and possible means to address those issues and the nature of analyses and policy options that might help in addressing the issues.

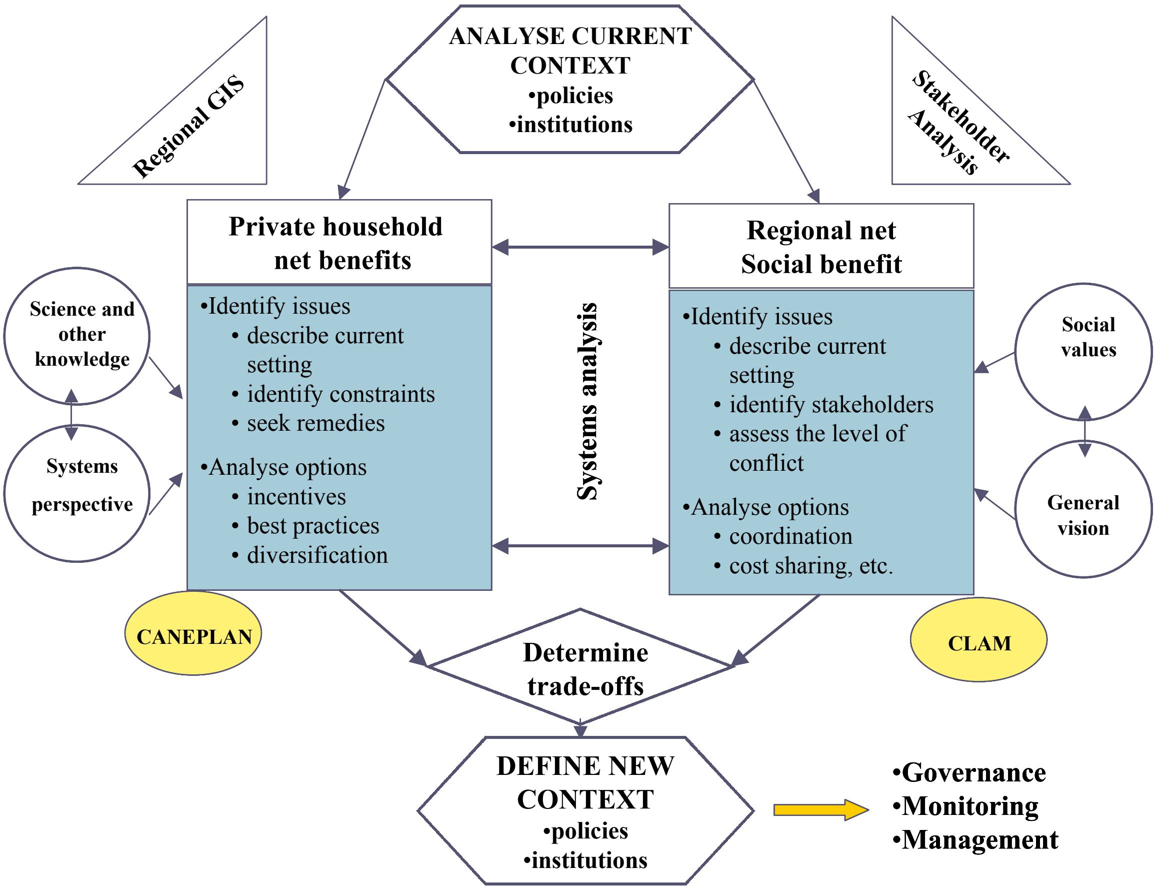


Figure 2: The integrated assessment framework

In this structure, CANEPLAN represents a farm level mathematical programming model of the type discussed in Qureshi et al (2001) and Mallawaarachchi, Hall and Phillips (1992). CLAM represents a regional allocation model of the type Mallawaarachchi and Quiggin (2001). The rationale for a focus in environmental management at the interface of farm and regional level is outlined in (Mallawaarachchi, Rayment and Grundy 2001). The basis of implementation of this framework as a user-friendly tool for quantitative analysis is illustrated in the next section.

3.6 Model design

The framework links between regional and enterprise level activities. It provides a method to represent sufficient detail and user flexibility to incorporate variability at the farm level and the complexity of the operating environment of the Sugar Industry at the regional level (Figure 3). The section of the diagram outside the dotted square represents the regional level operating environment and the section within the square represents the farm/enterprise level operating environment, modelled in CANEPLAN.

To make this system operational and suitable for repeated use with alternative input data to create a ‘tailor made’ version of CANEPLAN for each user, we have used a series of templates suitable for customisation. These templates representing generic whole farm multiperiod optimisation models can be modified using instructions received from the user through the interface. Depending on the nature of instructions received, the system develops a custom farm model to uniquely represent the farm being analysed. Each of these model templates has been tested with representative farm data to verify their accuracy and suitability for adaptation within the interface. As these models are incorporated in a modular fashion, new models may be attached to the system with ease. Model templates currently in use vary with respect to industry structure, dominant technology and known limitations for a given region, such as acid sulphate soils risk. Customisation process allows the user to specify parameters for prices, management, technology and the resource base (Figure 4).

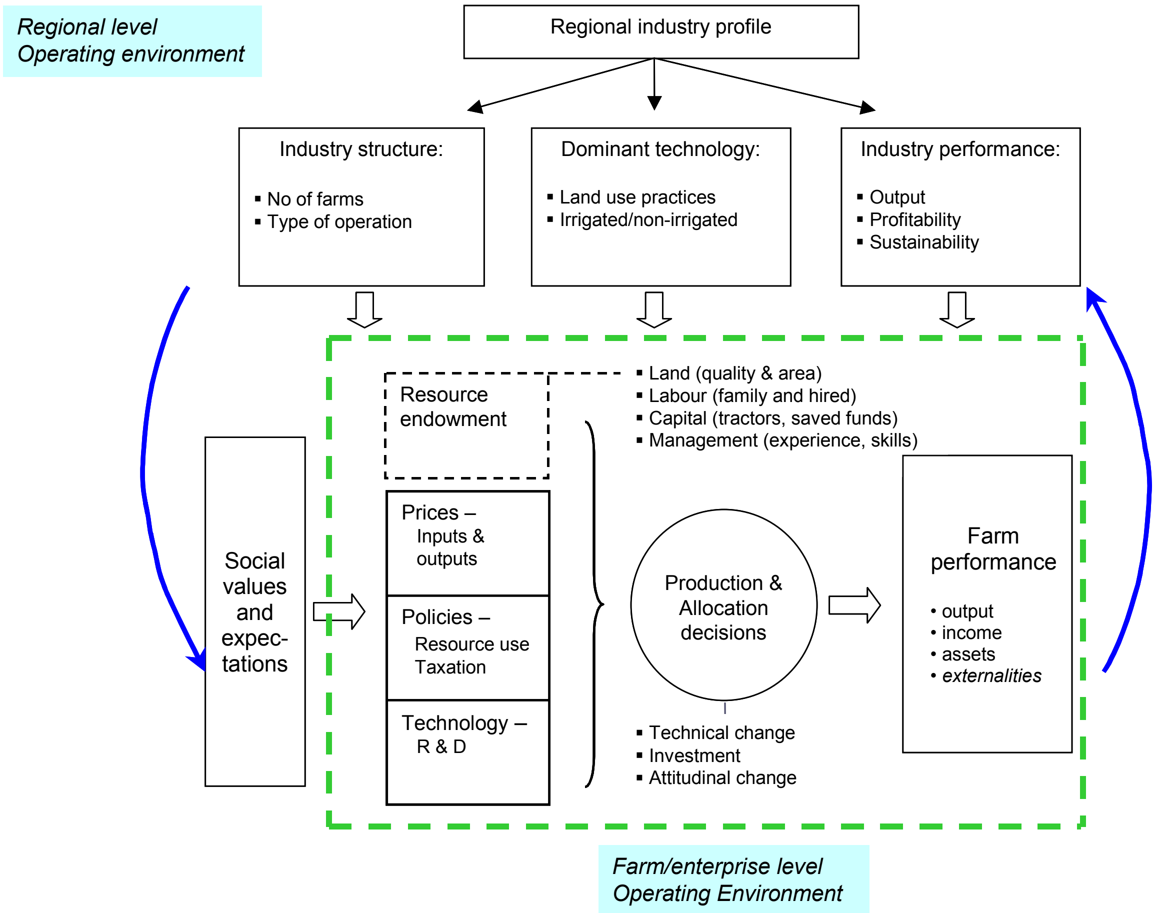


Figure 3: Operating environment and interactions between enterprise and regional levels

The two interconnecting components representing the enterprise and regional scale decisions allows the system to be used to addresses three questions at the two scales: (1) analyse the current context, (2) determine desired changes to respond based on current structure, and (3) how can a new context be defined. It can also be used to identify modalities (policies and institutions) to support that process in terms of governance, monitoring and management. Through repeated simulations, alternative scenarios can be developed with changes to key policy variables, resource parameters of technological coefficients to examine their influence on farm and regional performance and selected environmental outcomes (Figure 3).

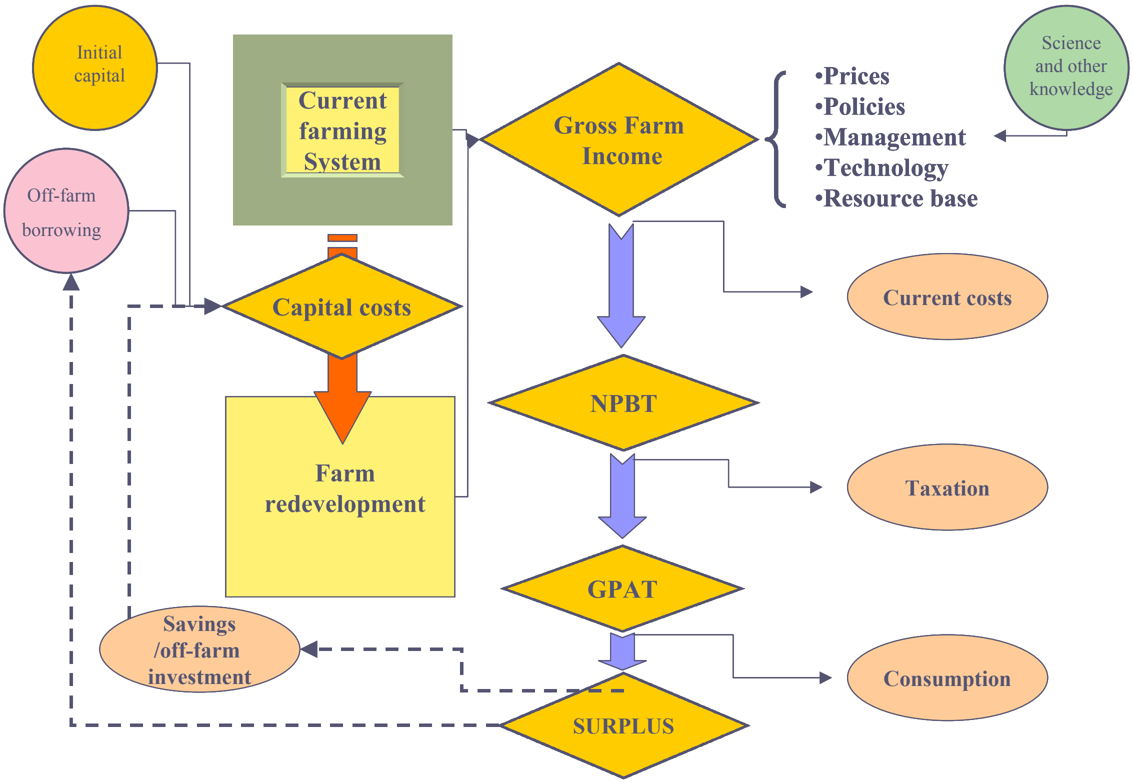


Figure 4: Activity flow chart for CANEPLAN

3.7 The current state and the way forward

Our current research is extended towards performance modelling, prediction and optimisation of best practice environmental management options, with a focus on optimal allocation of land under environmental constraints at the regional and enterprise scale. Currently FarmEasy is complete as a prototype using a Visual Basic interface to prepare data sets for input to GAMS optimisation software and to provide user-friendly outputs in Excel. Excel reports are generated from GAMS output using internal data transfer functions. The questions guiding data input and Excel reports can be easily modified or new forms can be added to the current system.

The interactive modelling system is composed of four main components linked through the Visual Basic interface. A questions module incorporating a set of templates to gather user data; modelling tools incorporating CANEPLAN specified in GAMS, a report generator that produces user-friendly output from GAMS runs; and an information storage and retrieval system to maintain user data for subsequent analysis. The data collated in this manner may be used to develop regional profiles and to assist with comparisons between different performance groupings identifiable based on common characteristics.

Although this system works sufficiently to meet current objectives, there are some drawbacks :

- Licence problems associated with GAMS and similar products.
- GAMS installation is separate to the Visual Basic FarmEa$y product.
- The tool can only be used in computers with both Excel and GAMS already installed. This restricts the use of the current version of FarmEa$y to only a few potential users.
- Moreover, as researchers need to physically liaise with the growers to obtain information and to conduct analyses, only a limited number of growers will benefit from the tools.

However, it would be possible for FarmEa$y to be moved to a database driven web system. The system can be installed in a central place or places of industry choice. This would alleviate the above-mentioned system drawbacks.

3.7.1 Moving to a web-based system?

In a web-based system, the data, question templates, modelling tools, report generator, and user data could be stored and operated on a remote server (Figure 5). A web-based system has the following advantages:

- The user will not have to install any software, thus alleviating licence problems.
- Users will have the option to choose reporting formats and alternative methods of data entry.
- Researchers will have greater flexibility to develop more functionality and add other suitable models with relative ease.
- The researchers will have access to the data from users immediately and can easily carry out data analyses, adjust or try new models on real data and get frequent user feedback.

To implement a web-based system, a web server with a Relational Database Management System such as ACCESS will be necessary. The modelling tools necessary to run FarmEa$y will need to be installed on this machine or on a machine that has a TCP/IP protocol reachable by FarmEa$y web system. The diagram below gives an indication of the web-based modelling system (Figure 5).

In both the current system as well as in a future web-based system, the user will interact with the interface represented above the green line in the above diagrammatic representation. However, user feedback and experience gained by researchers through further on-field applications will allow improvements and amendments to the modules represented below the green line to increase its effectiveness as a decision-support tool.

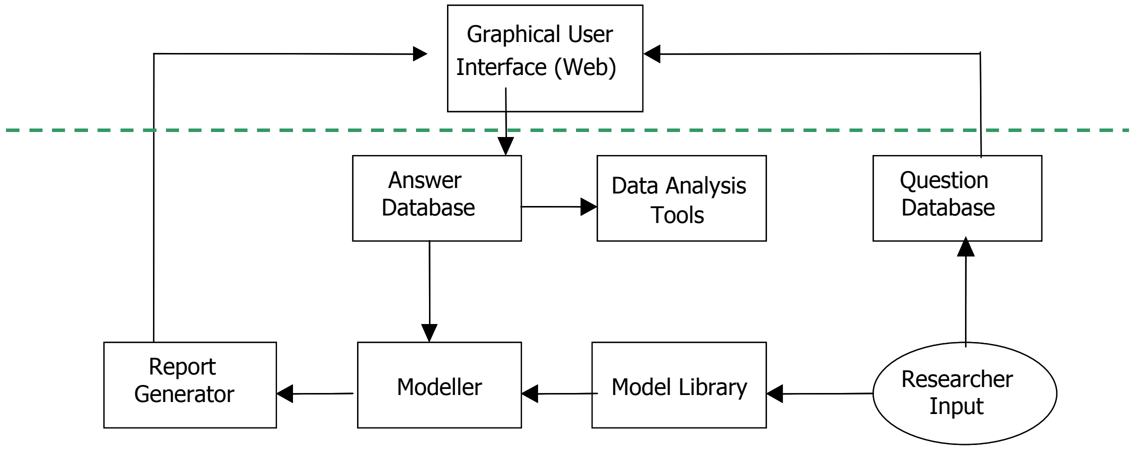


Figure 5: Components of the modelling system

4 FarmEa$y applications

4.1 Risk-based assessment of farm management options

The linking of scientific principles and process understanding to generate problem-specific solutions is a key requisite for effective environmental management at an operational scale. This is particularly true where management is taken to embrace all aspects of the solution process from problem analysis, formulating strategy, selecting policy instruments, to implementation and evaluation.

As highlighted in Mallawaarachchi, Grundy and Rayment (2002), from the perspective of industry, in the contemporary business setting, environmental management cannot be treated as a peripheral activity aimed at meeting external constraints. Rather environmental damage need to be considered as a wasteful activity and means to coordinate activities towards a prevention strategy is needed. Therefore, environmental policy should emerge as a mechanism to facilitate coordination between industry and the community. The broader concept of environmental planning, which goes beyond land-use decision-making and embraces the concept of spatial planning, including interactions between governments, markets and civil society may be used as a useful delivery mechanism to meet this challenge. To facilitate such deliberations, however, the industry needs to have access to analytical tools that can assist them in developing and evaluating scenarios for management alternatives.

The system has also been tested for its suitability as an aid to assessing profitability of proposed cane farm developments at the planning stage (Rayment 2001). In this respect, the tool may find a routine use in the cane land assignment process by the industry.

4.2 Insights from land-use studies[2]

Land use studies undertaken at CRC Sugar followed a risk-based approach to resource allocation and policy design at catchment, local area and farm/enterprise scales. These three scales correspond to both the spatial variability in resource attributes and reflect widely used decision scales in contemporary resource use planning.

4.2.1 Broad area risk assessment

The rationale in this assessment was to employ spatial data manipulation and modelling techniques to analyse commonly available resource attribute and production data (climate, soils, geology, terrain, topography, land-use etc.) in a GIS to define a rating scheme for sites of comparable resource quality. Sites may be rated for alternative uses ranging from crop production to conservation. To target management and policy restrictions, variable risk profiles for relevant environmental concerns were developed. In a detailed study of the Lower Herbert catchment of north Queensland, the values of conservation uses were estimated using non-market valuation methods following the choice modelling approach to assist the land allocation (Mallawaarachchi et al 2001). Procedure adopted for delineating land suitability rankings is illustrated in Figure 6. Such rankings were used in conjunction with economic values for different land uses (Table 1) to determine best-practicable land uses for alternative sites in a given broad area.

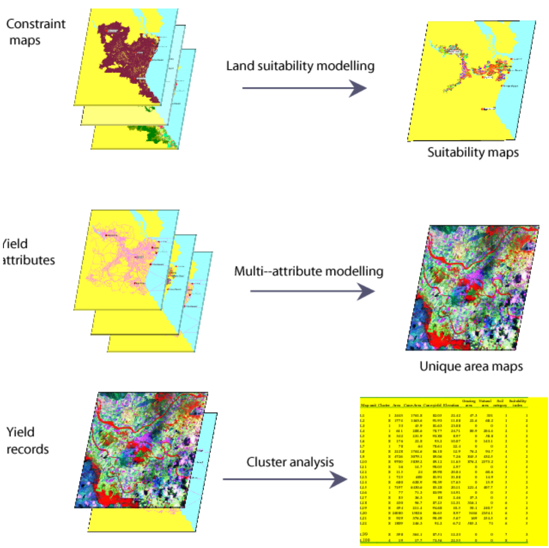


Figure 6: Scientific assessment of resource capability

Use of the regional economic optimisation model, CLAM, for this allocation enabled the strategies for optimal resource use to be drawn to incorporate management

2 This discussion draws on Mallawaarachchi, Grundy and Rayment (2002)

approaches that are technically sound, economically feasible and environmentally efficient (Mallawaarachchi and Quiggin 2001). This study of land allocation highlighted the role of environmental risk assessment and problems involved in measuring environmental values.

Table 1: Environmental and production values -Herbert

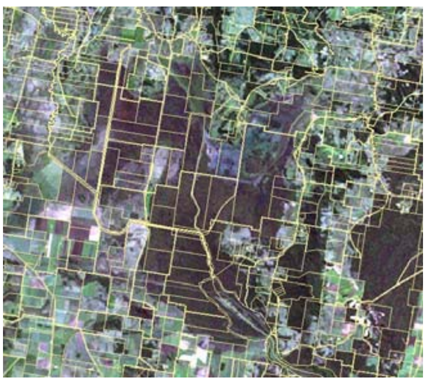
Land Use	Economic value ($/ha/year)
Grazing	34
Sugar cane	1500
Teatree woodlands	18
Wetlands and riparian areas	2812

Source: Mallawaarachchi et al (2001)

In another study area, in northern New South Wales, much of the area is of moderate or high risk of developing acid discharge from disturbance of the anaerobic acid sulphate layers in the subsoil. Some areas are currently under sugar cane but most of the area is currently used for cattle grazing. Five sets of data are available which allowed us to extrapolate economic modelling based on productive capability and / or environmental risk. These include:

- soil landscape mapping;
- multi-attribute mapping;
- a Digital Elevation Model and various derivatives;
- acid Sulphate risk mapping, and
- cadastral mapping.

No single data set has land suitability analysis such as that available for similar work in the Herbert. Consequently, a number of combinations were explored to capture the important spatial variation. All data is captured in a GIS and is readily altered as necessary and applied to the modelling task.



Management and natural landscapes units may not overlap. Spatial modelling can identify homogeneous groups where such overlap occurs and are suitable to target changed management.

Figure 7: Land management boundaries overlaid on resource attribute maps

The multi-attribute mapping was designed to provide spatial texture of a wide range of land management attributes including soils and soil qualities. While it does not provide a land suitability analysis for sugar cane, it does have a rudimentary limitation analysis based on soil physical limitations, which can be summed to produce a land capability classification. Most land in the study area has either severe or extreme limitations in the main due to seasonal or prolonged waterlogging. Cane growth would depend on effective drainage, which in turn must be sensitive to the acid sulphate potential.

Cadastral mapping for the area gives the spatial arrangement of managed properties and in some cases fields (Figure 3). A combination of biophysical attributes within management units could be used to divide the cropping possibilities into categories relevant to alternative management. The economic assessment could determine the viability of cane farming under such conditions, when the cost of problem-specific management is factored into the assessment. This information will aid the community in the study area to consider best-practise management strategies for using this land for maximum community benefit.

5 Conclusions

An integrated modelling approach that links activities at a farm and regional scale is outlined in this paper as a tool for technology assessment and policy analysis. Models are developed to address externalities in Australian sugar cane production in a coastal environment, but may be applicable in a wider context in examining ways to enhance greater environmental compliance through best practice management. The modelling system includes three interconnected segments: (1) production risk assessment for sugar cane and other crops; (2) assessment of management options to rank their suitability to mitigate risk; (3) determining economic feasibility of management strategies.

The best practice management options developed will be aimed at avoiding significant environmental impact; recognising the interest of the community and other stakeholders; promoting system scale solutions to land and water management; and seeking a commitment to continual improvement in performance. As the modelling system incorporates all aspect of production and their costs to determine feasible options, the system can be used to identify regionally effective solutions that are viable at the enterprise scale. As it is inevitable that certain activities may not be compatible in meeting resource management options at the two scales the system in full development could also be used to identify modalities (policies and institutions) to support the process of coordinating viable activities in terms of governance, monitoring and management.

Acknowledgements

This research was supported by the Cooperative Research Centre for Sustainable Sugar Production. Author has benefited from discussions with other team members, in particular George Rayment, Freeman Cook, Mike Grundy and Heiko Bohl. Ejaz Qureshi contributed to the development of the irrigation module of FarmEa$y and Juan Travaini assisted with the Visual Programming Interface development.

References

Department of Environmental Protection 1996, *Achieving Best Practice Environmental Management*, Department of Environmental Protection, Perth.

Environmental Protection Agency 1995, Overview of best practice environmental management in mining, Environmental Protection Agency, Canberra.

Ervin, D. and Schmitz, A. 1996, 'A new generation of environmental programs for agriculture', *American Journal of Agricultural Economics*, vol. 78, no. 5, pp. 1198-1206.

Forster, John, and Browne, Michael 1996, *Principles of Strategic Management*, Macmillan, Melbourne.

Greiner, R. 1999, 'An integrated modelling system for investigating the benefits of catchment management', *Environmental International*, vol. 25, no. 6/7, pp. 725-734.

Kay, J. J., Regier, H. A., Boyle, M. and Francis, G. 1999, 'An ecosystem approach for sustainability: addressing the challenge of complexity', *Futures*, vol. 31, no. 7, pp. 721-742.

Lichtenberg, E., Strand, I. and Lessley, B. 1993, 'Subsidizing agricultural non-point source pollution control: targeting cost sharing and technical assistance', *In* Russell, C., and Shogren, J., (eds.), *Theory, Modeling and Experience in the Management of Non-point Source Pollution*, Kluwer, Boston.

Mallawaarachchi, T., Blamey, R. K., Morrison, M. D., Johnson, A. K. L. and Bennett, J. W. 2001, 'Community values for environmental protection in a cane farming catchment in Northern Australia: a choice modelling study', *Journal of Environmental Management*, vol. 62, no. 3, pp. 301-316.

Mallawaarachchi, T., Grundy, M. J. and Rayment, G. E. 2002, 'Developing science-based policy options to maximise economic and social benefits from environmental management: insights from the Australian sugar industry', *4th Queensland Environmental Engineers Conference,* Brisbane Convention Centre, 30-31 May 2002.

Mallawaarachchi, T., Hall, N. H. and Phillips, B. 1992, 'Investment in water saving technology on horticultural farms', *Review of Marketing and Agricultural Economics*, vol. 60, pp. 191-204.

Mallawaarachchi, T. and Quiggin, J. 2001, 'Modelling socially optimal land allocations for sugar cane growing in North Queensland: a linked mathematical programming and Choice Modelling study', *Australian Journal of Agricultural and Resource Economics*, vol. 45, no. 3, pp. 383-409.

Mallawaarachchi, T., Rayment, G., Cook, F. and Grundy, M. 2001, 'Externalities in cane production and environmental best practice', Paper presented to AARES2001 *45th Annual Conference of the Australian Agricultural and Resource Economics Society,* Stamford Plaza, Adelaide, 23 - 25 January.

Qureshi, M. E., Mallawaarachchi, T., Wegener, M. K., Bristow, K. L., Charlesworth, P. B. and Lisson, S. 2001, 'Economic evaluation of alternative irrigation practices for sugarcane production in the Burdekin Delta', Paper presented to AARES2001 *45th Annual Conference of the Australian Agricultural and Resource Economics Society,* Stamford Plaza, Adelaide, 23 - 25 January.

Rayment, G. E. 2001, *Environmental and economic evaluation of a proposal to grow sugar cane on Glendower leases, Beaudesert region, South-east Queensland*, Natural Resource Sciences, NR&M and CRC Sugar, Indooroopilly.

Stanley, D. L. 2000, 'The economics of the adoption of BMPs: the case of mariculture water management', *Ecological Economics*, vol. 35, pp. 145-155.

Walter-Jørgensen, A. 1998, 'Sustainable strategies for agriculture - a holistic approach to analysis', *Paper presented at Nordic Seminar on Sustainable Agriculture, Stockholm, September 10-11*.

Young, M. 2000, Opportunities to improve resource and environmental management, Policy and Economic Research Unit, CSIRO Land and Water, Adelaide.