National Land & Water Resources Audit
An Initiative of the Natural Heritage Trust

NATURAL RESOURCE MODELS IN THE RANGELANDS

A REVIEW UNDERTAKEN FOR THE NATIONAL LAND AND WATER RESOURCES AUDIT

May 2004

Natural Heritage Trust

Helping Communities
Helping Australia

An Australian Government Initiative

Natural Resource Models in the Rangelands, *A Review Undertaken for the National Land and Water Resources Audit, May 2004*

CSIRO Sustainable Ecosystems
306 Carmody Road
ST LUCIA
QLD 4067

This project was managed by Mr. Blair Wood, Executive Director - National Land & Water Resources Audit under funding from the National Heritage Trust. Contact details: info@nlwra.gov.au

Table of Contents

1. Background

(a) National Land and Water Resources Audit context

The National Land and Water Resources Audit has been contracted by the Australian Department of Agriculture, Forestry and Fisheries to provide an analysis of the data and information needs underpinning sustainable grazing land uses in the Australian rangelands.

The Audit facilitated the development of a proposed Collaborative Rangelands Information System (NLWRA, 2001 “Rangelands – Tracking Changes. Australian Collaborative Rangelands Information System”). This initiative is now being implemented via a partnership between the Australian, State and NT Government and the CRC for Desert Knowledge.

The Audit required an analysis of current natural resource management models in use by institutions, agencies and land managers to identify the data and information that are informing these models. An analysis of the data needs, data currency and the identification of the custodians of these data sets are required. The project will not require the collection of new information, however the identification of proposed modelling activity and likely data and information needs could be included.

(b) Project Purpose

To prepare a report on natural resource management models available for use in Australia’ s rangelands and the extent of their use.

(c) Objectives

The objectives of the project are to:

(i) Compile a list of natural resource management models currently in use in the rangelands and

(ii) Identify the data and information needs of these models. In particular the fundamental datasets (time independent and time dependant) that are used to inform these models

(iii) Identify the custodians of these data sets

(iv) Identify where there are gaps in the required information

2. Models in the rangelands

(a) Why use models in the rangelands?

Rangelands are highly complex agro-ecological systems subject to considerable rainfall variability. This spatial and temporal heterogeneity, when combined with a complex socio-economic environment, means that it is almost impossible to use empirical studies to gain a comprehensive understanding of how rangelands respond to factors such as climate, fire, grazing, invasive species, and management because field or case studies are constrained to specific locations and short time frames (usually 5-10 years or less), and are very costly. Simulation modelling tools provide an alternative where the complex dynamics of rangeland systems is captured in computer code, the model is validated, and then used to predict how the system responds to climatic, edaphic, biotic, economic or management factors. Models can be used in conjunction with land managers to explore a range of scenarios or options that help to inform understanding of system complexities and assist with decision-making.

A number of models relevant to natural resource management have been developed and used to different degrees in the rangelands. Some of these have been developed for a single purpose or for a limited number of objectives or for a limited area of application, while others are much more general in their application. The input requirements for different models vary widely and this obvious implications for their use: for models with large input requirements it may not be possible to provide all the necessary information so their use can be limited; conversely some simple models may be able to be widely used but their output may be of limited value. Knowledge of the data needs for particular models is critical to any decisions about their use in particular situations, and also for assessing the appropriateness and value of model outputs.

(b) History of model development and use in Australia's rangelands

Conceptual models have been used since studies of the rangelands commenced but the widespread development of quantitative models did not occur until computers became readily available in the 1960s. These early models were biophysical process models that described how systems function that could be used to predict future conditions and likely responses to planned actions.

These early models were often research models built for a number of purposes – to organise and structure current knowledge, to focus attention on knowledge gaps, to a foster multidisciplinary approach, and as an effective means to study the behaviour and interactions of complex systems (Carlson et al. 1993). Many of these models closely reflected the interests of their developers and considered only a few of the total suite of resources (e.g. pasture growth, soil nutrient availability). Their development was often dominated by the system or region where their developers worked and this made it difficult to transfer them to other regions or limited their value in other regions.

In the 1980s there was a great deal of interest in the development of computer-based decision-support systems (DSS). Initially many of these were existing simulation models with a specially developed “front-end”. As there name suggests these systems were to be able to assist decision makers and often used biophysical models to evaluate alternatives. They frequently included a financial component to support the biophysical model.

Carlson, D.H., Thurow, T.L. and Jones, C.A. (1993) Biophysical simulation support models as a foundation of decision support systems. In Decision Support Systems for the management of Grazing Lands. (Eds J.W. Stuth and B.G. Lyons) UNESCO and The Parthenon Publishing Group, Carnforth, UK.

3. Model review process and methodology

The project was undertaken by a project manager, two project officers and the involvement of an Expert Reference Group. The Expert Reference Group had considerable experience in natural resource models and rangelands and who could efficiently identify the various hydrological, ecological and production-economic models in use in the rangelands, the advantages and disadvantages of these various models, and where there are gaps in approaches and in information (Objectives (i) and (iv). The project officers were responsible for contacting the custodians of the models identified by the Expert Reference Group and collating the required information on the various models (Objectives (ii) and (iii)). The project manager took responsibility for managing the project process and writing the report. The make-up of the project team and expert reference group is listed in Table 1 and the capabilities of the project team and expert reference group are detailed in Appendix 1.

Table 1. Make-up of project team and expert reference group

Role	**Name**	**Organisational Affiliation**
Project Manager	Andrew Ash	CSIRO Sustainable Ecosystems, Brisbane
Project Officer	Cam McDonald	CSIRO Sustainable Ecosystems, Brisbane
Project Officer	Adam Liedloff	CSIRO Sustainable Ecosystems, Darwin
Expert Reference Group	John Carter	Queensland Department of Natural Resources, Mines and Energy, Brisbane
Expert Reference Group	Mark Howden	CSIRO Sustainable Ecosystems, Canberra
Expert Reference Group	John Ludwig	CSIRO Sustainable Ecosystems, Atherton
Expert Reference Group	John McIvor	CSIRO Sustainable Ecosystems, Brisbane
Expert Reference Group	Greg McKeon	Queensland Department of Natural Resources, Mines and Energy, Brisbane
Expert Reference Group	Mark Stafford Smith	Desert Knowledge CRC, Alice Springs

The project commenced with the Expert Reference Group meeting in Brisbane on Monday March 8. The purpose of this meeting was to determine the detailed approach needed to best meet the requirements of the National Land and Water Resources Audit tender.

The group developed a number of criteria to assess the various models that it believed would meet the needs of the National Land and Water Resources Audit. Models were broken down into four groups or classes defined as:

I. directly relevant to the rangelands and are currently in use
II. directly relevant to the rangelands and are under development or not in widespread use as yet
III. models that are directly relevant to the rangelands but are for various reasons no longer in use
IV. models not directly designed for rangeland use but are being used or can be used in the rangelands e.g. fairly generic hydrological models or climate models.

Category (I) and (II) models were identified as essential to collect detailed information on their scope, data inputs and parameterisation. Eighteen criteria were developed for these models and put into a template document to be completed (Appendix 2). For category (III) and (IV) models it was decided that only the first ten criteria of those listed in Appendix 2 would require information. Category (IV) models represent a very “grey” area in terms of applicability to the rangelands as they encompass either quite general models that maybe relevant to the rangelands (e.g. large scale hydrological or climate models) or more specific models that were developed for non-rangeland environments but may have some minor relevance in the rangelands. As such this category of models is certainly not exhaustive and is meant to be more indicative of the types of models on the periphery of rangeland application.

In addition to these formal categorisation of models a number of models were encountered during the model search that were not formally assessed but a short description is included in a miscellaneous model section.

Based on their experience in the rangelands the Expert Reference Group then compiled a draft list of models that would be appropriate to review. The project officers were then given responsibility to construct a database of contact details for the custodians of the various models and for models in categories (I) and (II) seek assistance from the custodians in completing the templates. Category (III) and (IV) models were completed by members of the project team or the Expert Reference Group. In contacting the various model custodians the project officers became aware of other models and, where appropriate, these models were added to the list to be reviewed. A web search was also conducted to pick up any additional models. During the review process, a few of the models were removed from the list because details were too sketchy or they weren't considered relevant enough to be included. Where information could not be obtained from model custodians (unavailable or too busy in the time-frame of this project), the project team completed the template. A list of the models that have been included in this study and the contact details of the custodians are contained in Appendix 3.

4. Detailed model descriptions

Category 1 - These models are directly relevant to the rangelands and are currently being used

1. AussieGRASS
- national spatial pasture growth model

A. OVERVIEW

Purpose/Objective – AussieGRASS arose from a need to provide an objective assessment of drought. By applying the soil water balance and pasture growth model, GRASP, on a 5 km grid nationally AussieGRASS provides near real time map and data products and seasonal outlooks for Australia's rangelands to achieve (1) assessment for drought financial assistance support; (2) climate risk assessment for grazing enterprises and governments; and (3) information on general environmental conditions to support sustainable management of natural resources.

Keywords – pasture growth, utilisation, drought, land degradation, soil water balance, seasonal climate forecasts

Key contact/s –
John Carter
Department of Natural Resources & Mines
80 Meiers Road
Indooroopilly Qld 4068
Email: *john.carter@nrm.qld.gov.au*
Tel: (07) 3701 7093

John Carter (development, validation, calibration)
Beverley Henry (Coordinator, forecast product development)
Dorine Bruget (Programmer)
David Ahrens / Alan Peacock (products and web)
Greg Mckeon (Climate risk assessment)
Grant Stone (Stock numbers data)
Neil Flood (Programmer)

Model status – the model in its current form has been operational since about 1996. Development is continuing in regard to adding increased functionality. Operational running, ongoing calibration and validation and, subject to availability of resources, research are currently supported by the Queensland government and subscriptions from NSW, SA, WA and NT. The development of AussieGRASS was funded by RIRDC and the Climate Variability in Agriculture Program (CVAP) but currently, the program has no external funding from R&D corporations. Operationally the daily time-step model is run at the end of each month both for present conditions and in forecast mode using the SOI-phase seasonal outlooks for the coming three months. Products are typically made available by the third day of each month on the LongPaddock website. For those States providing funds to support the operation of AussieGRASS, map products are publicly available, while data (ERDAS Imagine files) and additional products are available on a password protected site. The model could be run each day using current climate data from BoM & SILO and could potentially incorporate NWP forecasts for short-term projections. Any forecast system that produces year-types could be linked to AussieGRASS to produce outlooks. Preliminary work has linked AussieGRASS to a

Global Circulation Model to allow research on drivers of climate variability and climate change in Australia.

Ownership/Availability – Queensland Government (40%), Land & Water Australia (from previous Land & Water Australia funding) (30%), SA, WA, NT, NSW (30%) (5% each SA DEHAA, Agriculture WA, NT DENR, NSW DLWC, NSW Agriculture)

For those States supporting AussieGRASS (currently with annual contracts) as an operational system, map products are publicly available, while data (ERDAS Imagine files) and additional products are available on a password protected site. The model is run on a 0.05^{o} (approx. 5km) grid and all products are available on this scale.

History of development – the spatial model was first developed by the state government (then DPI) for Queensland in the early 1990s to provide objective assessment of the drought to support submissions to the Australian government for financial assistance. The model was extended nationally in about 1995 in collaboration with leading rangeland scientists from state agencies in NSW, SA, WA, and NT (see 6 above), with funding from LWA through the CVAP program.

Documentation – see GRASP description

Brook, K.D. and Carter, J.O. (1994). Integrating satellite data and pasture growth models to produce feed deficit and land condition alerts. *Agricultural Systems and Information Technology Newsletter* 6.2: 54-56.

Brook K.D., Carter J.O., Danaher T.J., McKeon G.M., Flood N.R. and Peacock A. (1992). The use of spatial modelling and remote sensing to forecast drought-related land degradation events in Queensland. In *Proceedings of the Sixth Australasian Remote Sensing Conference*, Wellington, New Zealand 1,140-149.

Carter, J.O., Hall, W.B., Brook, K.E., McKeon, G.M., Day, K.A., and Paull, C.J. (2000). Aussie GRASS: Australian Grassland and Rangeland Assessment by Spatial Simulation. In *Applications of seasonal climate forecasting in agricultural and natural ecosystems – the Australian experience.* (Eds G. Hammer, N. Nicholls and C. Mitchell.) pp. 329-49. Kluwer Academic Press, Netherlands.

Carter, J.O., Bruget, D., Hall, W.B. and Collett, L. (2002) Using satellite data to calibrate a continental scale model of pasture production. In: *Proceedings 11th Australasian Remote Sensing and Photogrammetry Association Conference*, Brisbane, Queensland, Australia September 2002

Carter, J., Bruget, D., Hassett, R., Henry, B., Ahrens, D., Brook, K., Day, K., Flood, N., Hall, W., McKeon, and Paull, C. (2003). Australian Grassland and Rangeland Assessment by Spatial Simulation (AussieGRASS). In *Proceedings of the National Drought Forum: Science for Drought* 15–16 April 2003. Brisbane, Queensland, pp. 152–159.

Day, K.A., McKeon, G.M. and Carter, J.O. (1997). Evaluating the risks of pasture and land degradation in native pasture in Queensland. Final report for Rural Industries and Research Development Corporation project DAQ124A.

Day, K.A., Rickert, K.G. and McKeon, G.M. (in press). Agricultural drought monitoring in Australia. In *Agricultural Drought Monitoring Strategies in the World.* (Ed. V.K. Boken). Oxford University Press.

Dyer, R., Café, L. and Craig, A. (2001). The AussieGRASS Northern Territory and Kimberley Rangeland sub-project Final Report. Queensland Department of Natural Resources and Mines, Brisbane.

Hall W., Bruget D., Carter J., McKeon G., Yee Yet J., Peacock A., Hassett R., Brook K. (2001) *Australian Grassland and Rangeland Assessment by Spatial Simulation (AussieGRASS)*. Final report for the Climate Variability in Agriculture Program.

Hassett, R.C., Wood, H.L., Carter J.O. and Danaher, T.J. (2000). A field method for statewide ground-truthing of a spatial model. *Australian Journal of Agricultural Research* 40: 1069–79.

Henry B.K., Carter. J.O., Day, K.A., McKeon G. M. and Bruget D. (2004) Management of climate variability in extensive grazing systems. *Proceedings Outlook 2004 Conference,* 2–3 March 2004, Canberra.

Jeffrey S.J., Carter J.O., Moodie K.B. and Beswick A.R. (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling and Software* 16/4, 309-330.

Paull C, Cliffe N, Hall W (2001) Australian Grassland and Rangeland Assessment by Spatial Simulation, Extension sub-project, QNR9, Final Report for the Climate Variability in Agriculture Program 1-41.

Richards, R., Watson, I. Bean, J. Maconochie, J., Clipperton, S., Beeston, G., Green, D. and Hacker, R. (2001). The Aussie GRASS Southern Pastures sub-project Final Report. Queensland Department of Natural Resources and Mines, Brisbane.

Roxburgh, S.H., Barrett, D.J., Berry, S.L., Carter, J.O., Davies, I.D., Gifford, R.M., Kirschbaum, M.U.F., McBeth, B.P., Noble, I.R., Parton, W.G., Raupach, M.R. and Roderick, M.L. (2004) A review of net primary productivity estimates for the Australian continent *Global Change Biology* (submitted)

Tupper, G., Crichton, J., Alcock, D. and Mavi, H. (2001). The Aussie GRASS High Rainfall Zone Temperate Pastures sub-project Final Report. Queensland Department of Natural Resources and Mines, Brisbane.

Links to other models – outputs of AussieGRASS are used by ABARE farm performance model; AussieGRASS provides soil water initiation for GCM climate simulations and can take forecasts from GCM models:

Syktus, J., McKeon, G. Flood, N., Smith, I. and Goddard, L. (2003). Evaluation of a dynamical seasonal climate forecast system for Queensland. In *Proceedings of the National Drought Forum: Science for Drought* 15–16 April 2003. Brisbane, Queensland, pp. 160–173.

Objective assessment – in 2002 AussieGRASS was reviewed for LWA by an expert panel headed by Professor Henry Nix. The review team identified a need for error mapping for AussieGRASS and some progress has been made on Monte Carlo analysis to quantify uncertainty. The review however concluded that:

"The reviewers feel strongly that further investment …would have high pay-offs, considering the strong foundation and the functioning of the interdisciplinary team assembled for the project. Not to capitalise on their tremendous achievement, through continued funding and policy support, would be yet another Australian tragedy of failing to follow through on what is a major breakthrough……….Most importantly, the interdisciplinary team assembled for this project should be allowed to continue their great work."

AussieGRASS would benefit from additional observational data (pasture biomass and cover) from southern improved pastures to increase the robustness of calibration. The equations and parameters describing ground cover are inadequate. Additional calibration of model stream flow estimates and ground cover is needed. Improved calibration of the water balance could be achieved by using additional satellite data and stream flow data. Better estimates of soil fertility and particularly improved estimation of seasonal nitrogen availability would help improve pasture growth estimates in wet years. It is still unclear if inclusion of full a CN model will improve model estimates or just add to errors because of parameter uncertainty. It would take a minimum of 2 FTE's for 3 years to adequately cover these areas of development.

The major limitation for describing current conditions is the low density of real-time rainfall stations in many regions. Forecast skill for rainfall and other climate variables limits prediction of future pasture growth.

B. DETAILED MODEL DESCRIPTION

Model features – the model is coded largely in FORTRAN 90 with some file reading subroutines in C. It runs in both vector and parallel processing mode on a CRAY SV2 supercomputer but has been compiled and run on other platforms. The model runs on a 0.05 degree grid cell for all of Australia. The time step is daily and is routinely run from 1890 to 12 months in the future. The model is quite empirical.

Model processes – model process include a full water balance with evaporation, transpiration, runoff, drainage etc., and plant growth by radiation interception, transpiration or regrowth from reserves. Growth is regulated by soil water, nitrogen and temperature. Green leaf cover is fully dynamic. Herbivory, fire and detachment remove growth. Trees compete for nitrogen, water and solar radiation, but in the operational version, do not grow. In the current operational version N uptake is specified by parameters rather than a dynamic CN model.

Minimum data sets required –

- Daily rainfall
- Daily Minimum temperature
- Daily Maximum temperature
- Daily pan evaporation mm
- Daily solar radiation Mj (total, direct beam, flat surface)
- Daily average VP (hpa)
- Tree basal area
- Stock numbers at standard weights (Beef, sheep, dairy, macropods, feral, others)
- Soil water holding capacity for 4 layers (wilting point and field capacity)
- Fire scars as detected by NOAA/ MODIS satellites

Parameter sets –

- Transpiration use efficiency
- 4 temperatures describing a ramp function for growth
- Frost starting and frost killing temperature
- Potential rate of regrowth from tussock and seed
- Soil water index at which above ground growth stops
- Soil water index that can support 50% green cover
- Green biomass that gives 50% green cover
- Detachment rates (summer and winter)
- Maximum nitrogen uptake
- Maximum and minimum nitrogen concentrations in pasture
- Proportion of soil layer 3 available to grasses
- Yield at which animal intake becomes restricted

Development/Validation data – validation of the GRASP model capability has been carried out against an extensive array of point data. The spatial model has been calibrated and validated (independent subset) against nearly 500,000 field observations of pasture biomass. The model is also well calibrated to a spatially explicit data dense time series of greenness data from satellites (NDVI). Other data used to test model calibration are historic average stream-flow, animal production and stocking rate statistics from ABS, drought declaration statistics, ground and satellite measured cover data (see documentation section for references).

AussieGRASS was tested in an inter-model comparison study of continental NPP by CRC Greenhouse Accounting. (see Roxburgh *et al* 2004).

Sensitivity analyses – model optimisation is most commonly carried out in a manual operation using NDVI, observed pasture biomass and estimated total cover.

Automated model calibration can be carried out using a Genetic Algorithm or the PEST package. The PEST package generates an estimate of parameter sensitivity. Code to produce parameter sets by the Monte Carlo method is under development. There is no inbuilt uncertainty propagation and model performance is usually judged against observed data.

Model output –

- Monthly growth, percentile growth
- Total standing dry matter, percentile standing dry matter
- Runoff , percentile runoff
- Curing index
- Total cover %
- Green cover %
- N uptake
- Soil water
- Live weight gain
- Wool growth
- Synthetic NDVI

All internal variables (e.g. components of the water balance) are potentially available as outputs and can be made available as absolute, relative or as forecasts at some future time.

Application – the primary products from AussieGRASS are present and forecast simulations of pasture growth and pasture TSDM. These products with derived products of pasture utilisation, ground cover, potential run-off to streams are used in extension and by graziers for operational decision support to better manage for Australia's variable climate, i.e. to minimise variability in farm income and to minimise the risk of degradation through over-grazing.

(See e.g. McKeon, G.M., Hall, W.B., Henry, B.K., Stone, G.S. and Watson I. W. (Eds.) (2004). *Pasture degradation and recovery in Australia's Rangelands: Learning from History.* Department of Natural Resources and Mines, Queensland. Natural Resource Sciences Publishing.)

2. Breedcow / Dynama
- herd budgeting package

A. OVERVIEW

Purpose/Objective – profitability comparisons for different herd and property development options and projections (in units of 10 years) of herd structure, net profit, cash flow, assets, debt, net worth and return on assets

Keywords – extensive, beef, rangeland, profit, financial, budget, investment analysis.

Key contact –
W.E.Holmes,
Principal Agricultural Economist
Department of Primary Industries and Fisheries
PO Box 1085, Townsville, Qld.
Email: *bill.holmes@dpi.qld.gov.au*
Tel: (07) 4722 2663

Model status – fully operational and commercial, supplied and supported by the author and QDPIF.

Ownership/Availability – IP resides with Queensland DPIF. The package is available for purchase from DPI Bookshop or from the author at DPIF, Townsville. It is supplied with illustrative data only. Other data may be available from government users in Qld, NT and WA.

History of development – the package was developed as a personal toolkit which became a departmental toolkit and ultimately a fully commercial product for family beef producers, large pastoral companies, consultants, banks, accountants, valuers, lawyers, aboriginal land corporations, educational institutions and government primary industry departments. The first application was developed about 1980, first staff version was in 1988, and first commercial version in 1990. Evolution has been through nine spreadsheet-based platforms, through DOS and Windows, and is currently Windows based using Visual Baler authoring software. First staff release was of just two applications – Breedcow stable state herd simulator, providing herd structure and gross margins output, and Dynama multi-year model providing financial projections based on herd structure projections. The package now comprises nine applications based around four themes (see Detailed Model Description). All development and commercialisation was by the author.

Documentation – hard copy manual comprises 150 pages covering budgeting principles, accounting background and software application. More limited descriptions, and screen views, are provided on website *http://www.dpi.qld.gov.au/breedcowdynama/*

Holmes, W.E. (2004). *Breedcow and Dynama Herd Budgeting Software Package*, Version 5.03 for Windows 95, 98, Me, XP, NT and 2000. Training Series QE99002, Queensland Department of Primary Industries and Fisheries, Townsville.

Links to other models – nil, but used to analyse examples for MLA Edge Network Grazing Land Management education modules.

Objective assessment – Breedcow and Dynama package is intended for options analysis (from a profit standpoint) and for financial projections. Its greatest strength is that it is firmly based on projections of herd dynamics. A perceived weakness from a biological standpoint of the Dynama component of the package is that year by year variation is dealt with by user input, with no provision for random or otherwise variable generation of animal growth and fertility parameters – or for that matter of price parameters. This does not seem to worry the primary users. When we can reliably predict future rainfall, there will be more reason to factor in fluctuating parameters.

B. DETAILED MODEL DESCRIPTION

The Breedcow and Dynama herd budgeting package comprises nine programs (including support utilities) grouped around four business analytical themes:

- Where are we now and where are we headed? Uses Dynama program with support from TaxInc (calculates livestock trading profits for taxation estimates, and estimates taxable income form the plan) and MonthCFl (enables first year of Dynama budget to be split across months to calculate monthly cash flows and monthly working account balances). Support programs are Prices (net prices calculator) and AECalc (adult equivalents calculator).
- Is there a better way to run the herd? Uses Breedcow model, or the Bcowplus variant of Breedcow which allows more options in the handling of sales, spaying and allocation of adult equivalents. Better management options identified in Breedcow are then tested more thoroughly in Dynama. Support programs are Prices and AECalc.
- Change as an investment. Applies investment analysis concepts to comparing two Dynama files – without change and with change – to determine overall capital investment in a program of change, and the return on that investment. Can be used for 10 or 20 year analyses. InvestAn may also be used as a standalone investment analyser. InvestAn calculates Net present Value (NPV) of change, Internal Rate of Return (IRR) if applicable, Annualised Return of the NPV, and year and amount of peak investment or debt. InvestAn also incorporates menu access to standard interest rate procedures of compounding and discounting and converting lump sums to annuities and vice versa.
- When the wheels fall off – dealing with unplanned (forced or opportunistic) sales and purchases. Destock program calculates gross margins from narrowly defined groups of cattle, such as empty cows, out-of-season calvers, lead of the steers, tail of the steers. Priority for forced sales goes to those groups which will provide the necessary reduction in stock numbers, or the necessary raising of cash, whilst doing least damage to future income (i.e. groups with lowest prospective gross margins). Purchases should (obviously) give first priority to groups offering the best gross margin per unit.

There is a large degree of data interchange among programs, mediated through menu commands. Most obviously, data files generated by the Prices and AECalc programs may be accessed by Breedcow, Bcowplus and Dynama programs to enter complete price and AE rating sets (these entries can alternately be made manually without reference to Prices or AECalc programs). TaxInc and MonthCFl programs can import data from Dynama, or can be used as standalone programs. InvestAn is designed to import data from Dynama files but may be used as a standalone investment analysis tool. Bcowplus can import from the less complex Breedcow data files. Dynama can import branding and death rates, variable costs and (if real data does not exist) synthesised stable state herd structures from Breedcow or Bcowplus. Dynama may also import sales policies (used for AutoSales and AutoSpay formulas) from Breedcow and Bcowplus which enable a budget plan to trend towards and eventually stabilise on a proposed future herd structure.

Model features – Breedcow and Dynama package programs are written using Visual Baler. This is a spreadsheet based development tool, so key spreadsheet features remain such as the use of a cursor, the capacity to see the whole worksheet, and watching output change as inputs are changed. Users cannot see or change formulas or insert or delete sections. Data can be entered only in designated (coloured) data cells. Users can view only that part of each workbook in the "viewport". Only the input data is saved. Models do not include any hard wired assumptions – all data required must be supplied by users, with the exception of some data for later years which is copied from previous year by "allow override" formulas. These are special formula cells which can be overridden (as in a normal spreadsheet) but which can be restored ("deoverridden") to re-establish default values (unlike a normal spreadsheet).

Model processes – herd dynamics driving profit comparisons, accountancy processes, and investment analysis processes.

Minimum data sets required – branding and death rates (may be specified per age group or applying to all ages), husbandry costs and prices (Breedcow, Dynama and Destock), fixed costs, capital transactions, assets and liabilities, loan details (Dynama and derivatives), sales policies (Breedcow and Dynama). All data is supplied by users except for the example data sets provided with installations and used to illustrate the manual.

Parameter sets – branding and death rates, sale prices for all age/sex classes, fixed and variable costs, sales decisions, current assets and liabilities, future capital transactions.

Development/Validation data – careful checking of formulas and macros to ensure correct computation, and user experience for up to 16 years to find unintended outcomes.

Sensitivity analyses – this is up to the user although it is facilitated by the capacity to transfer in various Prices files (e.g. expected prices, best possible, worst possible) in quick succession to test price sensitivity. Sensitivity to branding and death rates can be tested very quickly in Breedcow (and Bcowplus) but less quickly in Dynama.

Model output – herd structures (stable state and over time), relative profitability of options, financial projections over 10 years (or units of 10 years) of net profit, cash flow, assets and liabilities, net worth, and return on capital.

Application – business analysis, options and analysis, business improvement.
Applications have included:

- Restructure of property portfolio by a major pastoral company to accommodate a move into younger male turnoff and feedlot finishing.
- Analysis of a woody weed control program ($2m plus) for a major pastoral company, input for comparative outcomes of action/no action supplied by stations managers. Comparative outcomes and expenditure for control modelled in Dynama and InvestAn. Findings presented to Company Board indicating satisfactory IRR (return on funds to be invested), approval of program by board.
- Analysis of improved land management practices for Grazing Land Management Edge Network educational packages. Indicated which practices are most profitable.
- Analysis of property purchase and management options by Indigenous Land Corporation.
- Analysis of property purchase and refinancing proposals by grazier users.
- Estimation of benefits from research (and extension) proposals for applications to funding bodies.
- Demonstration of benefits from PDS (Producer Demonstration Site) at field days.
- Collection of data and application of "truth serum" in DPI Local Best Practice project. Breedcow program was used on screen to collect data (opinions) and display the

outcomes of that data (if inconsistent with what was actually being achieved, then the data was revisited).

- Options analysis for DPI (and now also NTDBIRD) Smart Manager project. Producers modelled their current situations in a special version of Bcowplus, and then compared these representations with modelled outcomes from changed husbandry or grazing management practices. Serious proposals for change were modelled in Dynama to determine achievable "pathways to change" (overcoming the cash flow hurdles).
- Use by law firms in compensation cases and other disputes over ownership shares in herds.
- Use by banks for loan assessment, and by producers to present cases to banks.
- Use by extension officers from Qld, NT and WA to test extension ideas, demonstrate benefits to clients, encourage clients to get a better grip on measures of productivity (branding rates, deaths, weights), and to better understand for themselves the dynamics of herds in the face of changing technology and markets.
- Analysing drought response options and recovery plans.
- In the past Breedcow and Dynama were also used extensively for analysing impact of Brucellosis and Tuberculosis Eradication Campaign on individual producers.

The current (Windows) version of Breedcow and Dynama has approximately 300 users. The DOS version that preceded it had about 350. Current users include the owners of at least 2 million cattle. Its influence through consultants, government users etc. extends beyond this figure.

3. CENTURY
– a model for soil carbon and nitrogen dynamics

A. OVERVIEW

Purpose/Objective – the Century model was built to simulate soil carbon and nitrogen dynamics of grassland / cropping systems and has been developed also for forest and savannah systems. The model has been developed to incorporate many land management practices (irrigation, fertilisation, harvesting, fire, cultivation, grazing etc) to calculate the impact of these management actions on soil carbon stocks and fluxes.

Keywords – pasture growth, forest growth, soil carbon, soil nitrogen, carbon isotopes, crop management, CO_2 response, carbon cycle, nitrogen cycle.

Key contact/s –

Dr Bill Parton (Author and main developer)
Natural Resources Ecology Lab
Colorado State University
USA
Email: *billp@nrel.colostate.edu*

John Carter (development, validation, calibration for Australian pasture communities)
Department of Natural Resources, Mines and Energy
Email: *john.carter@nrme.qld.gov.au*
Tel: (07) 3896 9588

Chris Chillcott, Ken Day, Joe Scanlan (NRM&E)

Model status – development of CENTURY is still occurring by the author and by the Natural Resources Ecology Lab (NREL) Colorado State University. Current emphasis in the USA (DAYCENT) is towards calculating emissions of non CO_2 gasses (methane and nitrous oxide). Development in the monthly time-step version is an improved forest growth model. Development of a new fire regime model based on the Macarthur fire models is likely. In Australia (J.O. Carter), modelling of isotopes C^{14} has been improved, charcoal formation and partitioning to passive pool has been added, effects of changing atmospheric C^{13} added, de- mineralisation of N changed for desert soils, and pH effects of decay in waterlogged systems added.

Ownership/Availability – the model is available for download from the web. Source code can be obtained on application from the developers.

History of development – the original developer of the model is Dr Bill Parton (NREL), Colorado State University. Model development began in the second half on the 1980s. Bill Parton is supported by programmers and post-doctoral students. He has spent time in Australia for several years working on CENTURY development and application. Several versions of the model are available: CENTURY 4, CENTURY 5 and DAYCENT. CENTURY 4 was developed for DOS/UNIX environment, CENTURY 5 is a more user friendly version of CENTURY 4 adapted for Windows and has upgraded some aspects of soil erosion. DAYCENT is a daily time-step version specifically adapted to estimate sinks and sources of non CO_2 greenhouse gasses.

Documentation – documentation can be downloaded from the web, both printed manual and electronic documentation are available.
http://www.nrel.colostate.edu/projects/century/documentation1.htm

Links to other models – the core algorithms for soil carbon processes have been incorporated into the models CENW and CENW-TG (Kirschbaum) and a subroutine is available for use with GRASP. CENTURY has been used with the output of general circulation models to study impacts of climate change on regional and global carbon stocks.

Objective assessment – the major strengths of the model are: (1) its widespread use on an international level; (2) comprehensive carbon and nitrogen models; (3) most common land management practices can be simulated; and (4) carbon isotopes can be modelled. The major limitation is the very large array of parameters used to describe processes and management actions. Users should devote a reasonable amount of time to learning how to use the model. Fixed partitioning of growth to tree components and lack of ability to incorporate stochastic fire reduce ease of use in northern Australia. Development activity to address these last two issues in underway.

B. DETAILED MODEL DESCRIPTION

Model features – CENTURY 4 is a mixture of Fortran 90 and C, later versions are in C.

Model processes – processes include a full water balance with evaporation, transpiration, runoff, drainage etc. Plant growth is calculated from a potential maximum and decremented for soil water availability, temperature and nutrient availability. Growth (trees and grass/crop) can be removed by fire, grazing or harvest. Soil carbon and nitrogen (with capability of phosphorus and sulphur) is modelled with 3 soil pools with different decay rates for organic matter. Carbon ^{13} or carbon^{14} can be modelled. The CENTURY 4 and 5 versions run at a monthly time-step.

Minimum data sets required –

- Monthly rainfall
- Monthly minimum temperature
- Monthly maximum temperature
- Soil texture
- Latitude
- Soil depth
- Nitrogen inputs in rainfall / fertiliser
- Fire regime
- Management (grazing, cultivation etc)

NB (the model can be run with average or stochastic climate and these are often used during model spin-up).

Parameter sets –

- Potential rate of growth under ideal conditions
- Nitrogen input from rainfall and fixation
- Nitrogen concentration ranges in plant parts
- Lignin content of litter
- Optimum temperature for growth
- Maximum LAI
- Biomass removal with fire
- Tree kill with fire
- Detachment rates

Development/Validation data – CENTURY has been widely tested across many systems throughout the world. In Australia it has been tested on cropping systems on the Darling

Downs, Mulga thinning experiment at Charleville and pasture systems in Queensland and South Africa. Model inter-comparisons with GRASP have been carried out by Day *et al* (2003) for South African wooded and non wooded grasslands. A formal model inter-comparison of CENTURY, GRASP and several other tree/grass models (Charleville mulga and sites in other countries) was attempted in the USA. The results have been presented at workshops and a formal publication is in draft form (Contact Joe Scanlan NRM&E, Toowoomba). CENTURY has been used to simulate C, N, C^{13} and C^{14} on 31 sandy soil sites across Australia as part of CRC-Greenhouse Accounting research activities. These sites range from rainforest to arid spinifex. With some adaptation, the model could be parameterised for most sites although C^{14} and CN ratios for some sites remain difficult to simulate. Publication is in early draft form.

CENTURY was tested in an inter-model comparison study of continental NPP by CRC Greenhouse Accounting. (see Roxburgh *et al.* 2004)

Sensitivity analyses – model optimisation is most commonly carried out in a manual operation using observed soil C and N stocks. Preliminary studies of parameter sensitivities and automated model calibration using a Genetic Algorithm has been developed by J. Carter. There is no inbuilt uncertainty propagation and model performance is usually judged against observed data.

Model output –

- Total soil carbon
- Carbon in 3 pools (with isotope)
- Live and dead roots
- Live and dead grass (crop) tops
- Forest biomass
- Soil nitrogen
- Nitrogen in plant components
- CO_2 fluxes

Most internal variables (e.g. components of the water balance, C and N stocks, and fluxes for various plant and soil pools are available as outputs.

Application – the model has been used in many studies with recent emphasis on C and N balance under global change. Management of agricultural systems to maximise C stocks and minimise non CO_2 emissions. The model has been used to simulate the management of carbon dynamics of many and varied ecosystems across the globe. Currently CENTURY is being used to simulate changes in soil carbon with cropping on the Darling Downs, and investigate the relative effects of grazing and tree clearing on soil carbon stocks in Queensland rangelands.

Roxburgh, S.H., Barrett, D.J., Berry, S.L., Carter, J.O., Davies, I.D., Gifford, R.M., Kirschbaum, M.U.F., M^cBeth, B.P., Noble, I.R., Parton, W.G., Raupach, M.R. and Roderick, M.L. (2004) A review of net primary productivity estimates for the Australian continent. *Global Change Biology* (submitted)

Day KA, Maclaurin AR, Dube S., Hlatshwayo, A, Trevor, CL (2003). *Capturing the Benefits of Seasonal Climate Forecasts in Agricultural Management: Sub-Project 3 - Grazing Systems in Zimbabwe*. Final Report for the Australian Centre for International Agricultural Research (ACIAR), Project LWR2/96/215, 67 pp.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* 51:1173-1179.

Parton, W.J., J.W.B. Stewart, and C.V. Cole. 1988. Dynamics of C, N, P and S in grassland soils: a model. *Biogeochemistry* 5:109-131.

Parton, W.J., C.V. Cole, J.W.B. Stewart, D.S. Ojima, and D.S. Schimel. 1989. Simulating regional patterns of soil C, N, and P dynamics in the U.S. central grasslands region. Pages 99-108 in M. Clarholm and L. Bergstrom, editors. *Ecology of arable lands*. Kluwer Academic Publishers, Amsterdam, Netherlands.

Parton, W.J., B. McKeown, V. Kirchner, and D.S. Ojima. 1992. *CENTURY Users Manual*. Colorado State University, NREL Publication, Fort Collins, Colorado, USA.

Parton, W.J., D.S. Ojima, D.S. Schimel, and T.G.F. Kittel. 1992. *Development of simplified ecosystem models for applications in Earth system studies: the CENTURY experience*. Pages 281-302 in D.S. Ojima, editor. Earth system modeling. Proceedings from the 1990 Global Change Institute on Earth System Modeling, Snowmass, Colorado, USA. (689)

Parton, W.J., J.M.O. Scurlock, D.S. Ojima, T.G. Gilmanov, R.J. Scholes, D.S. Schimel, T. Kirchner, J-C. Menaut, T. Seastedt, E. Garcia Moya, Apinan Kamnalrut, and J.I. Kinyamario. 1993. Observations and modeling of biomass and soil organic matter dynamics for the grassland biome worldwide. *Global Biogeochemical Cycles* 7:785-809. (672)

Parton, W.J., and P.E. Rasmussen. 1994. Long-term effects of crop management in wheat/fallow: II. CENTURY model simulations. *Soil Science Society of America Journal* 58:530-536. (694)

Parton, W.J., D.S. Schimel, and D.S. Ojima. 1994. Environmental change in grasslands: assessment using models. *Climatic Change* 28:111-141. (696)

Parton, W.J., D.S. Schimel, D.S. Ojima, and C.V. Cole. 1994. A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. Pages 147-167 in R.B. Bryant and R.W. Arnold, editors. Quantitative modeling of soil farming processes. *SSSA Special Publication 39*. ASA, CSSA, and SSA, Madison, Wisconsin, USA. (695)

Parton, W.J., P.L. Woomer, and A. Martin. 1994. Modeling soil organic matter dynamics and plant productivity in tropical ecosystems. Pages 171-188 in P.L. Woomer and M.J. Swift, editors. *The biological management of tropical soil fertility*. TSBF/John Wiley & Sons, New York, New York, USA. (741)

Parton, W.J., J.M.O. Scurlock, D.S. Ojima, D.S. Schimel, D.O. Hall, M.B. Coughenour, E. Garcia Moya, T.G. Gilmanov, Apinan Kamnalrut, J.I. Kinyamario, T. Kirchner, T.G.F. Kittel, J-C. Menaut, O.E. Sala, R.J. Scholes, and J.A. van Veen. 1995. Impact of climate change on grassland production and soil carbon worldwide. *Global Change Biology* 1:13-22. (717)

Parton, W.J., D.S. Ojima, and D.S. Schimel. 1996. Models to evaluate soil organic matter storage and dynamics. Pages 421- 448 in M.R. Carter and B.A. Stewart, editors. *Structure and organic matter storage in agricultural soils*. CRC Press, Inc., Boca Raton, Florida, USA. (740)

Parton, W.J. 1996. Ecosystem model comparison: science or fantasy world. Pages 133-142 in D.S. Powlson, P. Smith, and J.U. Smith, editors. Evaluation of soil organic matter models using existing long-term datasets. *NATO ASI Series*, Vol. I 38, Springer-Verlag, Berlin, Germany. (759)

Parton, W.J. 1996. The CENTURY model. Pages 283-293 in D.S. Powlson, P. Smith, and J.U. Smith, editors. Evaluation of soil organic matter models using existing long-term datasets. *NATO ASI Series,* Vol. I 38, Springer-Verlag, Berlin, Germany.

Parton, W.J., M.B. Coughenour, J.M.O. Scurlock, D.S. Ojima, T.G. Gilmanov, R.J. Scholes, D.S. Schimel, T. Kirchner, J-C. Menaut, T. Seastedt, E. Garcia Moya, Apinan Kamnalrut, J.I. Kinyamario, and D.O. Hall. 1996. Global grassland ecosystem modelling: development and test of ecosystem models for grassland systems. Pages 229-266 in A.I. Breymeyer, D.O. Hall, J.M. Melillo, and G.I. Agren editors *Global change: effects on coniferous forests and grasslands*. SCOPE volume 56. John Wiley & Sons, Chichester, West Sussex, England. (789)

Parton, W.J., E.A. Holland, S.J. Del Grosso, M.D. Hartman, R.E. Martin, A.R. Mosier, D.S. Ojima, and D.S. Schimel. Generalized model for NOX and N2O emissions from soils. *Journal of Geophysical Research: Atmospheres* (in press).

Parton, W.J., M. Hartman, D. Ojima, and D. Schimel. 1998. DAYCENT and its land surface submodel: description and testing. *Global and Planetary Change* 19:35-48. (883)

4. FLAMES

- fire and landscape model for tropical savannas

A. OVERVIEW

Purpose/Objective – FLAMES is designed to simulate the long-term dynamics of a savanna tree stand given natural variation in rainfall and initial population structure and the effects of management practices and disturbances such as grazing and fire.

The model also allows for simulating the effects of weed invasion, drought, fire management, soil water processes such as infiltration and can be used to track changes in carbon sequestration and calculate greenhouse gas emissions from burning.

Keywords – fire, grazing, tree population, grass, litter, fuel, soil water, management, carbon

Key contact/s –

Adam Liedloff
Tropical Savannas Management CRC and CSIRO Sustainable Ecosystems
CSIRO Tropical Ecosystems Research Centre
PMB 44, Winnellie, Northern Territory, 0822
Email: *adam.liedloff@csiro.au*
Tel: (08) 8944 8446

Garry Cook
CSIRO Sustainable Ecosystems
Email: *garry.cook@csiro.au*

Model status – the model is currently under development by the Tropical Savannas Management CRC (TSM CRC) and CSIRO Sustainable Ecosystems (CSE) and is now being used for initial validation simulations.

Ownership/Availability – IP for FLAMES is split equally between TSM CRC and CSE. The model code and user interface has been developed by TSM CRC with background model development and underlying processes developed by CSE and other acknowledged participants. The model is available in collaboration with the developers and has not been released for general use.

History of development – model development commenced in 2001 and the model is now being implemented into a range of TSM CRC and other projects. The model is currently a research tool and can be used in collaboration with the developers to investigate tree dynamics in tropical savannas.

Documentation – a full model description, manual and users guide is available.

Links to other models – the FLAMES model incorporates the eco-hydrology and rainfall intensity components of the Savanna.au model. These components are hard coded into the model.

Objective assessment – while developed for the tropical savannas, this model is capable of simulating the fate of any savanna tree stands given rainfall and fire regimes. It is capable of predicting historic drought events and providing a management tool for determining the effects of grazing and fire on tree populations and resulting carbon pools. The model is particularly effective at looking at compositional and structural changes in tree populations and how these affect the fate of a stand over a range of disturbances. As all parameters are available to the user (various access levels possible), the current model therefore requires a good understanding of all processes by the user to fully understand simulation results.

B. DETAILED MODEL DESCRIPTION

Model features –

Style and time-step

FLAMES is a process based, mechanistic model designed to simulate a single plot of trees (point based, default hectare) or a contiguous group of cells to represent a landscape (up to paddock or hillslope scale) with hydrological processes (runon and runoff) simulated between cells. Placement of trees within the hectare cell is not spatially explicit. The model runs on a number of time steps with rainfall and hydrological processes on a daily time step, mortality and grass production on a monthly time step and tree growth on an annual time step.

Spatial and Temporal capability

FLAMES is designed to simulate a single cell (hectare plot), but has the ability to simulate contiguous cells. While there is no limit to the number of cells that can be simulated, the model is only expected to simulate a paddock or hillslope (20x20 hectares). In terms of computation for large scale areas, we suggest that single representative cells be simulated and extrapolated to the landscape scale.

As trees are slow growing and thus present in the landscape for a number of years, the FLAMES model is designed to run for a long time periods to encapsulate the mortality, population structure and long term fire regime changes in the populations.

Language and Interface

The FLAMES model is written in Microsoft Visual C++ (V6.0) and distributed as an ActiveX Control and also as a model executable (.EXE).

The user interface (MYME – My Modelling Environment, Liedloff, 2004) is written in Microsoft Visual Basic (v6.0) with some graphical development (3D Tree Population Viewer) in Visual Basic .Net. The user interface controls all parameter entry, parameter checking prior to running the model, data management, error and warning handling and output control.

Model processes – tree growth, tree water use, tree mortality, grass production, grass water use, soil hydrology, infiltration, fuel, litter dynamics, decomposition, grazing, fire frequency, fire intensity, carbon sequestration, greenhouse gas emissions, re-sprouting potential.

Minimum data sets required –

- Daily rainfall files as obtained from Bureau of Meteorology (BOM) or SILO
- Average monthly 9 am and 3 pm temperature, humidity and mean and standard deviation wind speed from BOM
- Land unit for each cell simulated – tied to soil descriptions
- DEM of cells to provide run-off run-on capabilities with sink holes removed.
- Initial tree population (Delimited list of individual DBH, diameter at breast height for each Species or functional group present)

Parameter sets – all parameters can be accessed and set by the user as no values are hard coded into the model. This provides a large number of parameters, but equally makes the model extremely dynamic and controllable. A key set of parameters are required to initialise the model and provide management scenarios.

Fire

Fire regime, frequency, timing (month, am/pm), type (elliptical or fronting), minimum curing rates

Soil

Rooting depths

Textural information (% sand, silt, clay) or Bulk density and Particle density

Tree populations (multiple species can be used)

Mortality as a function of fire intensity

Drought mortality rates

Growth rates

DBH to canopy, biomass, water use, grass biomass relationships

Climate

Breakdown of daily rainfall into two events

Development/Validation data – FLAMES incorporates much of the published tree survival, recruitment and re-sprouting results from the Kapalga Fire Experiment undertaken in Kakadu National Park by CSIRO (Ecological Studies 169. Fire in Tropical Savannas: The Kapalga Experiment. Andersen, A., Cook, G. and Williams, R. Eds. 2003, Springer)

A full list of research results incorporated into the model is available in the user manual.

Sensitivity analyses – validation and sensitivity analysis is currently being undertaken to produce a FLAMES publication.

Model output – a large range of values can be generated by the model in Tab delimited ASCII files for easy importing into Excel or sent directly to Excel from the user interface. A 3D visual display (with walkthrough and user defined angle of view) is available to demonstrate the outcome of any simulation. This output provides a visual depiction of fire frequency, fire intensity, tree growth and tree mortality. This application can save individual frames and animated sequences.

Spatial output maps are also available to animate simulated changes over the duration of the simulation

Application – current and future uses of the FLAMES model include:

- ALFA. Arnhem Land fire abatement project
- TSM CRC Educational Tool for coursework
- Simulation of fire for Bushfires CRC project (Northern Territory Wildlife Park)
- Parameterisation for South African fire trials
- Invasion and management of woody and grassy weeds

5. GRASP

- soil water and pasture production model for Australia's rangelands

A. OVERVIEW

Purpose/Objective – GRASP is a 'pasture growth' model that combines a soil water model and a model of above-ground dry-matter flow. It has been built to meet specific objectives relating to grazing management of Australian rangelands: (1) objective assessment of drought and degradation risk in near-real time; (2) simulation of grazing management options including seasonal forecasting; (3) assessment of safe carrying capacity; (4) evaluation of impact of climate change and CO_2 increase; (5) reconstruction of historical degradation episodes; and (6) providing simulations of pasture growth for the industry-supported Grazing Land Management Package. GRASP has been used as a sub-model (subroutine) in other models: (1) assessment of impact of policy on Drought Exceptional Circumstances in terms of herd/flock dynamics and cash flow; (2) evaluation of management of mulga woodlands in terms of greenhouse gas emissions; (3) a component of the AussieGRASS system; and (4) a model incorporating the GoldenWing tree growth model.

Keywords – soil water, pasture growth, drought and degradation risk, climate risk assessment, seasonal climate forecasting, safe carrying capacity, grazing land management

Key contact/s –

Greg McKeon - Coordinator
Department of Natural Resources, Mines and Energy
80 Meiers Road
Indooroopilly Qld 4068
Email: *greg.mckeon@nrme.qld.gov.au*
Tel: (07) 3896 9548

John Carter – model development, AussieGRASS application
Ken Day – model development, model parameterisation and field trial analysis
Chris Chilcott – simulation application to GLM
Grant Fraser – runoff and soil erosion modelling
Jo Owens – soil water and drainage simulations
Grant Stone – field trial analysis and model validation
Cindy Trevor – simulations and report preparation
Peter Timmers – model development and parameterisation
Neil Flood – code development
Wayne Hall – wool production model
Rob Hassett – field validation

Model status – the model has been applied in simulation studies since 1982. It remains under continual development. The model is used operationally to meet the objectives listed above. A new pulse of model development is about to commence as part of an MLA-funded project. The model has been under operational testing and validation over the last 10 years.

Ownership/Availability – The model is available as a sub-routine based on one-to-one negotiation. The current version is owned by the Queensland Department of Natural Resources and Mines but has had contributed IP from a large number of agencies.

History of development –

1978 - The soil water balance model was developed by Ken Rickert.

1982 - A pasture growth model for black speargrass using climate indices was developed and used in simulations.
1982 – Specific diet selection model for percent nitrogen at Brian Pastures, SEQld.
1984 – Parameterisation of sown pastures and forage crops.
1987 – Model development specifically for native pastures using GUNSYNpD field data.
1991 – Inclusion of simplistic nitrogen model.
1993 – Inclusion of tree competition model.
1996 – Evaluation on all available DPI cutting trial data and DPI grazing trials.
1997 – Inclusion of CO_2 response.
1997 – General wool production model for western Queensland.
1998 – General cattle liveweight gain model for speargrass zone.

Documentation –

Rickert, K.G., Stuth, J.W. and McKeon, G.M. (2000). Modelling pasture and animal production. In 'Field and Laboratory Methods for Grassland and Animal Production Research'. (Eds. L. 't Mannetje and R.M. Jones). pp. 29-66 (CABI publishing: New York).

McKeon, G.M., Day, K.A., Howden, S.M., Mott, J.J., Orr, D.M., Scattini, W.J. and Weston, E.J. (1990). Management of pastoral production in northern Australian savannas. *Journal Biogeography* **17**: 355-72.

McKeon, G.M., Rickert, K.G., Robbins, G.B., Scattini, W.J. and Ivory, D.A. (1980). Prediction of animal performance from simple environmental variables. *Fourth Biennial Conference, Simulation Society of Australia*, Brisbane 1980. pp. 9-16.

Rickert, K.G. and McKeon, G.M. (1982). Soil water balance model: WATSUP. *Proceedings Australian Society Animal Production*. **14**: 198-200.

McKeon, G.M., Rickert, K.G., Ash, A.J., Cooksley, D.G. and Scattini, W.J. (1982). Pasture production model. *Proceedings Australian Society Animal Production*. **14**: 201-4.

Hendricksen, R.E., Rickert, K.G., Ash, A.J. and McKeon, G.M. (1982). Beef production model. *Proceedings Australian Society Animal Production*. **14**: 204-8.

Hall, W.B., McKeon, G.M., Carter, J.O. and Day, K.A., Howden, S.M., Scanlan, J.C., Johnston, P.W. and Burrows, W.H. (1998). Climate Change and Queensland's grazing lands: II. A review of models of animal production from native pastures. *The Rangeland Journal*. **20:** 174-202.

Scanlan, J.C. and McKeon, G.M. (1993). Competitive effects of trees on pasture are a function of rainfall distribution and soil depth. *XVII International Grassland Congress Palmerston North, New Zealand.* p2231-2.

McKeon, G.M., Ash, A.J., Hall, W.B. and Stafford Smith, M. (2000). Simulation of grazing strategies for beef production in north-east Queensland. in *Applications of Seasonal Climate Forecasting in Agricultural and Natural ecosystems.* The Australian Experience. Edited by G.L. Hammer, N. Nicholls and C. Mitchell. pp. 227-252.

Scanlan, J.C., Pressland, A.J. and Myles, D.J. (1996a). Runoff and soil movement on mid-slopes in north-east Queensland grazed woodlands. *Rangeland Journal* **18**, 33-46.

Owens, J.S., Silburn, D.M., McKeon, G.M., Carroll, C., Willcocks, J.R. and De Voil, R. (2003). 'Cover-runoff equations to improve simulation of runoff in pasture growth models', *Australian Journal of Soil Research*, **41**: 1467-1488.

Howden, S.M., Walker, L., McKeon, G.M., Hall, W.B., Ghannoum, O., Day, K.A., Conroy, J.P., Carter, J.O. and Ash, A.J. (1998). *Simulation of changes in CO_2 and climate on native pasture growth*. Final report for the Rural Industries Research and Development Corporation: Evaluation of the impact of climate change on northern Australian grazing industries (DAQ 139A), pp. 141-84.

Day, K.A., McKeon, G.M. and Carter, J.O. (1997a). *Evaluating the risks of pasture and land degradation in native pasture in Queensland*. Final report for Rural Industries and Research Development Corporation project DAQ124A.

User documentation is described in:

Littleboy, M. and McKeon, G.M. (1997). *Subroutine GRASP: Grass production model, Documentation of the Marcoola version of Subroutine GRASP*. Appendix 2 of Evaluating the risks of pasture and land degradation in native pasture in Queensland. Final Project Report for Rural Industries and Research Development Corporation project DAQ124A.

Links to other models – GRASP has been used as a sub-model (subroutine) in other models: (1) in HerdEcon for assessment of impact of policy on Drought Exceptional Circumstances in terms of herd/flock dynamics and cash flow (Stafford Smith and McKeon 1998); (2) evaluation of management of mulga woodlands in terms of greenhouse gas emissions (Moore *et al.* 1997, Howden *et al.* 1999b).

Objective assessment – The strengths of GRASP are: (1) the robustness of the one-dimensional soil moisture model; (2) the ability to parameterise from field measurements for the variety of pastures in Australia's rangelands; (3) the continued development, evaluation and validation through close association with field applications.

The weaknesses of GRASP are: (1) the simplistic description of the pasture as a sward; (2) the lack of a nitrogen cycle model; (3) the lack of a dynamic tree model (now dealt with in the GoldenWing model).

The limitations of the model are: (1) situations where large changes in pasture composition occur from year-to-year; (2) application to high fertility situations, e.g. sown pastures; (3) failure to adequately simulate partitioning between roots and shoots; application to grazed shrublands.

B. DETAILED MODEL DESCRIPTION

Model features – the model is written in FORTRAN, available with a user friendly interface, e.g. WINGRASP or as a sub-routine, e.g. Cedar Version. Developers often use an older F77 version. The model is unabashedly empirical with a daily time-step. The model represents a point, i.e. no explicit spatial or grid modelling occurs.

Model processes – Model processes include a full water balance with soil evaporation, tree and grass transpiration, runoff and drainage. Plant growth is determined from radiation interception, transpiration or regrowth from grass basal area. Growth is regulated by soil water, solar radiation, vapour pressure deficit, temperature and nitrogen. Green cover is fully dynamic. Herbivory, fire and detachment remove standing dry matter. Trees compete for nitrogen and water.

Minimum data sets required – (1) daily climate data – rainfall, maximum temperature, solar radiation, pan evaporation, vapour pressure; (2) site characteristics include tree basal area; (3) stocking rate of sheep or cattle; (4) soil water holding capacity; (5) fertility as represented by peak nitrogen uptake; (6) temperature response of the sward. Average parameter sets have been developed for different pasture communities. A field methodology (SWIFTSYND) to collect a minimum dataset to parameterise the model is described in Day *et al.* (1997).

Parameter sets –

- Transpiration use efficiency
- 4 temperatures describing a ramp function for growth
- Frost starting and frost killing temperature

- Potential rate of regrowth from tussock and seed
- Soil water index at which growth stops
- Soil water index that can support 50% green cover
- Green biomass that gives 50% green cover
- Detachment rates (summer and winter)
- Maximum nitrogen uptake
- Maximum and minimum nitrogen concentrations
- Proportion of soil layer 3 available to grasses
- Yield at which animal intake becomes restricted

Development/Validation data – model development and validation is described for Queensland's native pastures in Day *et al*. (1997) including cutting and grazing trials. The following AussieGRASS reports include examples of model development with GRASP for other regions of Australia's rangelands where our field trial data were available.

Dyer, R., Cafe, L. and Craig, A. (2001). *The AussieGRASS Northern Territory and Kimberley Rangeland sub-project Final Report*. Queensland Department of Natural Resources and Mines, Brisbane.

Richards, R., Watson, I., Bean, J., Maconochie, J., Clipperton, S., Beeston, G., Green, D. and Hacker, R. (2001). *The AussieGRASS Southern Pastures sub-project Final Report*. Queensland Department of Natural Resources and Mines, Brisbane.

Tupper, G., Crichton, J., Alcock, D. and Mavi, H. (2001). *The AussieGRASS High Rainfall Zone Temperate Pastures sub-project Final Report*. Queensland Department of Natural Resources and Mines, Brisbane.

Sensitivity analyses – Sensitivity studies have been carried out as a development, however they have not been reported in any citeable document.

Model output – Outputs include: (1) components of the soil water balance; (2) dry matter flow; (3) nitrogen uptake; (4) animal production; (5) grass basal area; (6) soil erosion; (7) fire frequency; (8) composite variables for growth analysis and other model development, e.g. pasture utilisation.

Application – GRASP has been built to meet specific objectives relating to grazing management of Australian rangelands: (1) objective assessment of drought and degradation risk in near-real time (Carter *et al.* 2000); (2) simulation of grazing management options including seasonal forecasting (Ash *et al*. 2000, McKeon *et al.* 2000, Stafford Smith *et al.* 2000); (3) assessment of safe carrying capacity (Johnston *et al*. 1996, Hall *et al.* 1998); (4) evaluation of impact of climate change and CO_2 increase (Hall *et al.* 1998, Howden *et al.* 1999a); (5) reconstruction of historical degradation episodes (McKeon and Hall 2000); (6) pasture growth simulations for the Grazing Land Management Package; and (7) evaluation of historical climate variability, including El Niño-Southern Oscillation impacts in terms of pasture growth and other variables (McKeon *et al*. 1990).

6. GROWEST/GROWEST PLUS

- tool for assessment of seasonal growth for environmental planning and assessment

A. OVERVIEW

Purpose/Objective –

GROWEST PLUS provides a new software interface to the GROWEST model, that enables users to easily run the GROWEST program on 'real' time climate data, in point or grid form, and to undertake a range of spatial and temporal analyses via a graphical user interface. GROWEST PLUS was primarily developed as a tool for the Bureau of Rural Science's evaluations of Exceptional Circumstances' (EC) applications. The EC policy aims to provide assistance to producers undergoing rare and severe (predominantly drought related) events that are considered beyond the scope of normal risk management. Assessment of drought events for EC requires the ability to rank growing seasons in the historical record for the purpose of assessment of the rarity of an event (one of the criteria for the provision of EC assistance). The use of GROWEST PLUS in EC fulfils a requirement for analyses based on long-term 'potential' growth estimates. This provides valuable information relating to individual plant growing seasons that cannot be determined from climate data alone.

Keywords – pasture growth, crop growth, modelling, drought, seasonal reliability, climate

Key contact –

T. R. Brinkley
Bureau of Rural Sciences
GPO Box 858, Canberra ACT 2601
Email: tim.brinkley@brs.gov.au
Tel: (02)

Model status – the model is fully operational

Ownership/Availability – the GROWEST model is owned by the Centre for Resource and Environmental Studies at ANU, while the PLUS component is the property of BRS.

History of development – initial development of the GROWEST model was reported by Fitzpatrick and Nix (1970) and this model used weekly climate values derived from actual data. A later version was incorporated into the GROCLIM module and this allowed the model to use long-term monthly records, and by interpolation, do it for any point of known latitude, longitude and elevation in Australia. These were both point models. GROWEST PLUS has been developed by the Bureau of Rural Sciences (BRS) and Centre for Resource and Environmental Science (CRES) at the Australian National University (ANU) and can be run on a grid of points. The interface simplifies the task of accessing and organising numerous input and output files...

Documentation – the following publications describe much of the detail of GROWEST and GROWEST PLUS:

Fitzpatrick, E.A. and Nix, H.A. (1970). *The climatic factor in Australian grassland ecology*. In Australian Grasslands. (Ed. Moore, R.M.) pp. 1-26. (ANU Press: Canberra.)

Nix H.A. (1981). Simplified simulation models based on specified minimum data sets: the CROPEVAL concept. In *Application of remote sensing to agricultural production forecasting*. pp. 151-169. (Commission of the European Communities: Rotterdam.)

Brinkley, T.R., Laughlin, G.P. and Hutchinson, M.F. (in preparation) GROWEST PLUS – A tool for rapid assessment of seasonal growth for environmental planning and assessment**.**

Links to other models – none, other than the fact that GROWEST PLUS incorporates GROWEST

Objective assessment –
GROWEST is a simple model that provides a good estimate of the relative variability of potential growth for a region. GROWEST PLUS provides a simple and intuitive interface to analyse and visualise potential plant growth over regions using a time-series of real historical data. The use of conditional statistics to analyse seasonal reliability enhances the capacity to describe potential agricultural production beyond standard statistical measures. However, specifying the thresholds for this type of analysis often requires a good understanding of what percentage of relative seasonal growth translates to a viable crop or pasture. A weakness of the model lies in the need for input grid data to be formatted as ASCII grids and all grids must have the same extent and cell size. Also, the model does not permit spatial differentiation of the plant temperature regime when running on grid data. This means that maps summarising frequency of seasonal indices for a particular region may be inappropriate when applied to the whole of Australia.

B. DETAILED MODEL DESCRIPTION

Model features – GROWEST PLUS has been written using Java script and has an easy to use GUI. It runs on a weekly time-step with output on a weekly or monthly basis. GROWEST PLUS calls the GROWEST model, provides the relevant file names etc. runs it, then displays the analyses in graphical form.

Model processes – temperature, radiation, moisture and plant growth indices.

Minimum data sets required – actual weekly, actual monthly or average monthly maximum and minimum temperatures, radiation, rainfall and evaporation in a point or grid format.

Parameter sets – the two main parameters are:

- Soil characteristics including soil water capacity and soil type e.g. clay loam etc.
- Temperature regime e.g. C_3, C_4 etc.

Development/Validation data – GROWEST has been extensively tested in characterising plant growth (Nix *et al.* 1977; Nix 1981; Murray and Nix 1987; Blumenthal and Ison 1993). GROWEST PLUS displays frequency and probability information based on historical climate data.

Nix, H. A., McMahon, J. P., and Mackenzie, D. 1977. Potential areas of production and the future of Pigeon Pea and other grain legumes in Australia. Wallis, E. S. and Whiteman, P. C. In The Potential for Pigeon Pea in Australia, *Proceedings of Pigeon Pea* (Cajanus cajan(L.) Millsp.) *Field Day*. 1977. Dept, Ag., Uni. Qld., Australia.

Murray, M. D. and Nix, H. A. (1987). Southern limits of distribution and abundance of the biting-midge Culicoides brevitarsis Kieffer (Diptera: Ceratopogonidae) in south-eastern Australia: an application of the GROWEST model. *Australian Journal of Zoology* **35**, 575-585.

Blumenthal, M. J. and Ison, R. L. Use of water balance models to examine the role of climate in annual legume decline in southern Australia. *Proceedings of the 17th International Grassland Congress*. p61-62. 1993.

Sensitivity analyses – criteria can be tested as part of the analysis process.

Model output –

Indices of temperature, radiation, moisture and plant growth are calculated on weekly or monthly basis in a point or gridded format depending on input data. The output is displayed in the form of a map, but can be exported in ASCII format suitable for uploading into GIS software for further spatial analysis. The output can be either raw time series data for a particular cell or summary statistics of grids. The summary output provides frequencies and probabilities of events, or can return the index for a particular percentile. Similarly, indices over particular events (e.g. droughts) can be summarised.

Application –

The output indices of GROWEST PLUS may be used to analyse specific events (such as drought) or characterise growing season reliability (to manage environmental sustainability). Event analysis provides a means of analysing how a season or string of seasons ranks in the historical record.

However, GROWEST PLUS has broader applications beyond EC assessments. For example, it may be used in the assessment of broad scale crop or pasture growth potential over large regions. The analysis of seasonal growth reliability (using exceedance statistics) through the use of extended time-series climate data may have the potential to assist in risk management decisions for sustainable environmental and agricultural planning (Laughlin 2001).

Laughlin, G. P. (ed.) *Integrated Spatial Project*: Interim report to the Lachlan Catchment Management Committee. 2001. BRS ISP project Team.

7. RANGEPACK Herd-Econ

– a herd dynamics and property economics model for rangelands pastoral properties. (Description includes associated models – Herd-Econ v2, v3; HerdGRASP; HerdGRASP.XLS; RiskHerd)

A. OVERVIEW

Purpose/Objective – RANGEPACK Herd-Econ is a deterministic herd dynamics and property economics model normally intended for use at an enterprise level (Stafford Smith and Foran, 1990, 1992). It allows users to define a grazing enterprise of any number of animal classes by age groups, each of which has given biological (mortality, growth and reproduction) rates. The model then tracks animal numbers on a monthly timestep, subject to different buying and selling strategies and transfers between animal classes. The economics module uses animal numbers to adjust variable costs, and combines trading results with other expense and receipt items to generate a cash flow. Loans and taxation can be investigated although this is not the principal purpose. Herd-Econ was especially designed to look at the interactions between a variable climate and pastoral decision-making.

Keywords – grazing animals, population dynamics, economics, pastoralist, decisions, selling, buying, profit, equity, loans

Key contact –

Mark Stafford Smith
Desert Knowledge CRC
PO Box 2111, Alice Springs, NT 0871, Australia
Email: mark.staffordsmith@csiro.au
Tel: (08) 8950 7162

Model status – Herd-Econ versions 1-2 were sold commercially and well-tested. Subsequent versions have been used in a research environment only. No further development is currently occurring.

Ownership/Availability – the original IP for the model was held by CSIRO, with elements of development also supported by the Reserve Bank, the National LandCare Program, RIRDC, and LWRRDC (CVAP), as well as software sales and workshop fees. Since 1988, version 2 has been freely available at cost on a strictly *caveat emptor* basis, only supplied electronically on CD with electronic manuals and an extended library of examples. This software is now seriously outdated (though fast!) and must run in a Command Prompt window; no-one has sought a copy since about 2000. Versions from 3 on are only available to collaborators. Key datasets for the main projects are documented in the reports listed in the bibliography.

History of development – the original Herd-Econ was developed and released in 1988-90 (ver.1); this was sold commercially (about 100 copies sold). An update (ver2) was released about 1991 with much improved documentation but modest further functionality; about 150 updates and further sales were made. Special versions were released to limited users to handle mixed smaller herds in New Zealand; rabbit in New Zealand; and (weakly) mixed cropping/herds during 1991-93. At this time RANGEPACK Paddock was developed in a new Windows-based shell, and version 3 of Herd-Econ was also placed in this shell, but development resources were limited and the version was not released publicly. This version, which had a much more sophisticated command language, was used extensively in-house till about 1998, and HerdGRASP was built using it for the initial RISKHerd pilot study and the LUCNA project. All versions to this point were written in C. The full RISKHerd and Oceans-to-Farms projects included a re-write of the core functionality of Herd-Econ for research purposes in EXCEL (and Visual Basic), greatly simplifying the concept to its critical steps, and incorporating a stochastic simulator (similar to the @RISK add-in, which was used initially); the GRASP linkage was abstracted and simplified for this purpose (ca. 2001). At the same time a major linked package was written to handle all aspects of rural tax for RISKHerd. Finally, for RISKHerd and Oceans-to-Farms, evolutionary optimising code was integrated with the spreadsheet version of Herd-Econ. The core coding of Herd-Econ was mostly carried out by Mark Stafford Smith, with assistance from Oscar Bosman for versions 1 and 2, and field testing and use by Barney Foran; Michael Hope for version 3; and most of the spreadsheet versions have been written by Joe Breen, except for the tax package which was developed by Jeremy Cross.

Documentation – full bibliography attached below: a number of papers describing uses of Herd-Econ are not included. Version 2 documentation is available electronically in the volumes noted below.

Links to other models – the main link outside the RANGEPACK lab has been between Herd-Econ and GRASP. This necessitated positing linking functions between animal condition (or pasture parameters) and animal population parameters (birth and death rates, age and animal class specific where possible), making assumptions about the effects of different patterns of stocking through the year on the overall utilisation feedbacks on grass basal area used in GRASP, and, in longer runs, pasture condition feedbacks cf. Ash *et al*).

In early stages some comparisons of Herd-Econ with Dynama were made, but no model other than Dynama has sought to fill the same niche so it has not been possible to make inter-model comparisons.

Objective assessment –

Model functionality - Herd-Econ was designed to allow monthly decision-making on large properties to be mimicked with variable level of detail and realism, from simplistic overall annual herd patterns to very detailed monthly patterns by many animal classes and age groups. Versions 1 and 2 operated on the basis of 4 seasonal qualities defined in terms of their impacts on birth and death rates (and, potentially, management decisions). Given sufficient tuning it was found to be very good at patterning real property data, but this depended on a reasonable knowledge of animal birth and mortality patterns. The explicit linking of GRASP to Herd-Econ provided a mechanism to make the seasonal types more continuous, although this was dependent on relationships between animal condition and birth and death rates which are poorly known. Although the coding explicitly handled rounding errors on proportions of animals, these create still significant anomalies in small herds (where most individual animal classes contain less than ~100 animals), so that Herd-Econ works poorly on small farms. The original Herd-Econ was poor at dealing with the differential effects of different sequences of years on biological rates (e.g. birth rates after three bad years, compared to in the second bad year), even though it was good at demonstrating the effects on animal numbers and herd composition; HerdGRASP fixed this problem in principle. A variety of ways of simulating management behaviour (selling proportions of a herd or animal class, buying and selling to a target, etc) were implemented, but it was possible to think of additional behaviours not included. The financial component of Herd-Econ was originally intended to be a souped up cash-flow model, although simple loan and profit and loss handling was included; in particular limited attention was given to capital value other than that of stock. (The tax package subsequently included in RISKHerd handled all this and much more in a fully complicated way.)

Software and interface ease of use - for its time the original Herd-Econ Ver 1 and 2 was cutting edge in terms of a windowing environment with an internal command language separating modules in a way now commonplace in DDL communications. However, its flexibility was a double-edged sword, making it hard for those with limited computer-exposure to use. Its greatest use was therefore in workshop and consultancy situations. The subsequent interfaces have been more sophisticated, but the command language became much more complex and version 3 was poorly documented; consequently this became harder to use, although this did not matter since it was used only for research purposes by this stage. The spreadsheet version is again much simpler, and reasonably well documented in the RISKHerd series of reports.

Future effort - the concepts that Herd-Econ sought to elucidate are now more commonly found in other simulation treatments of rangelands pastoralism, and simpler spreadsheet models are able to capture most of the critical elements now that these can be identified. It would not now make sense to re-engineer the Herd-Econ software to bring it up to date. The greatest gaps to creating a simpler comprehensive model remain the linking animal condition/birth and death rate functions in managed herds, feedbacks from selective grazing pressure on key pasture species at critical times, and a complete understanding of pastoralist decision-making (where there is still a great deal of work to do – cf. Breen *et al* 2004).

B. DETAILED MODEL DESCRIPTION

Model features – Versions 1-2 in C and some assembler with add-in libraries handling windowing and printing functions; Ver 3 in Visual C and some assembler; spreadsheet version in EXCEL and Visual Basic.

Details of model function are given for different versions in the references listed below.

Model processes – details of model function are given for different versions in the references listed below.

Minimum data sets required – the stand-alone Herd-Econ versions require a sequence of year types, where those types are matched to appropriate biological rates; a "herd flow" structure showing how a particular property manages its animal classes; a series of key pastoralist decision-making criteria in terms of animal transfers, sales and purchases; and basic cash flow-related financial information (including sale and purchase prices). Optionally additional financial elements can be explored. Although on-property data can usually be elicited for the first 3 elements, comprehensive (let alone formal scientific) datasets for these remain very limited. The financial details, though often not collated, are reasonably readily acquired. Research and extension agencies are often poor at formulating the data needed for a set of regionally 'typical' examples for the first 3 elements; pastoralists are usually readily able to give specific data relevant for their property, but often with poor validation. This is problematic since these data almost entirely drive property profitability.

The linked models require much more information – only substantially problematic in the case of HerdGRASP, where reliable predictors for birth and death rates in commercial domestic situations remain elusive.

Parameter sets – key 'parameters' are:

- a "herd flow" (structure rather than parameter)
- birth, death and growth rates by animal class (and age) for up to 4 year types – precision and resolution depending on the purposes
- pastoralist decision criteria

- basic financial data

Herd-Econ really does not hard-wire any parameter (other than some reasonable constants such as the number of months in the year, etc), but does contain a number of assumptions about how liveweights are averaged across two sets of animals, and how to handle 'partial' animals at sales, etc (these are documented in detail in the Technical Manual). Also, it provides only a limited (though diverse) number of ways of implementing buying and selling decision-making.

The later linked versions introduce more assumptions, in birth and death relationships, etc, though these are all coded in the command language so formally are amenable to user change.

Development/Validation data – an extensive series of collaborative case studies with producers, consultants and agencies in the early years of Herd-Econ affirmed that the basic code ran correctly, given recognition of some key assumptions. With appropriate tuning, actual patterns of stock on properties (where sufficient records existed) could be mimicked well. However, there was always an element of circularity in this since there were rarely totally independent assessments of stock mortality and birth rates. Many of the case studies are documented in the references. An additional extensive series were made into information sheets, and the electronic versions of Herd-Econ Ver 2 included a library of these.

Sensitivity analyses – the original versions of Herd-Econ were fully deterministic, so were not designed to do this. These issues were extensively considered in later stochastic and optimising versions (see RISKHerd, LUCNA and Oceans-to-Farms reports). Formal internal sensitivity analyses were rarely performed (though see reports on data analysis for RISKHerd), but sensitivity analysis of outputs to changes in inputs was used extensively to help identify sensitive aspects of property function.

Model output – details of the extensive options for model outputs are given for different versions in the references listed below.

Application – Herd-Econ has mainly been used to explore what the implications of alternative pastoral management strategies and tactics are on property cash flow and profitability, given the underlying assumptions about how animal production rates respond to different years and year sequences.

Extensive simulation studies have been carried out with Herd-Econ – an estimated 40-60 by ourselves with versions 1 and 2 (reported in leaflets, electronic demonstration versions, and some papers such as Stafford Smith & Foran 1988, 1990, 1991, 1992; Foran *et al* 1990; Foran & Stafford Smith 1991; Stockwell *et al* 1991; Stafford Smith *et al* 1994; Hatch & Stafford Smith 1997, etc), and at least 100 more by Rosemary Buxton summarised briefly in the series of DroughtPlan reports (Buxton *et al*. 1995-1996, and Buxton & Stafford Smith 1996) and subsequently. These included sheep and cattle examples in Australia, mixed cropping studies in NSW, work on sheep (and rabbits) in New Zealand, Aboriginal killer herds, and communal farming regimes in South Africa. Later papers tend to be about the linked models.

Partial Bibliography (including only publications with Stafford Smith as one author).
All of the following refer to Herd-Econ (or one of its stable), sometimes descriptively, or in actual case studies, or in terms of more generic lessons learned from the approach.

Refereed writings, published

Stafford Smith, D.M. & Foran, B.D. 1988. Strategic decisions in pastoral management. *Austr.Rangel.J*. **10**, 82-95.

Stafford Smith, D.M. and Foran, B.D. 1990. RANGEPACK: the philosophy underlying the development of a microcomputer-based decision support system for pastoral land management. *J.Biogeography* **17**: 541-546.

Foran, B.D., Stafford Smith, D.M., Neithe, G., Stockwell, T, & Michell, V. 1990. A comparison of development options on a Northern Australian beef property. *Agric.Syst.* **34**: 77-102.

Foran, B.D., & Stafford Smith D.M. 1991. Risk, biology and drought management strategies for cattle stations in Central Australia. *J.Envir.Manage.* **33**: 17-33.

Stafford Smith, D.M. & Foran, B.D. 1991. Risks and returns: analysing the influence of climatic and market uncertainty on management strategies. *Proc.IV Intl.Rangel.Cong.*, Montpellier, April 1991, 831-833.

Stockwell, T.G.H., Smith, P.C., Stafford Smith, D.M., & Hirst, D.J. 1991. Sustaining productive pastures in the tropics 9. Managing cattle. *Tropical Grasslands* **25**: 137-144.

Stafford Smith, D.M., & Foran, B.D. 1992. An approach to assessing the economic risk of different drought management tactics on a South Australian pastoral sheep station. *Agric.Syst.* **39**: 83-105.

Stafford Smith, D.M., McNee, A., Rose, B., Snowdon, G., & Carter, C. 1994. Goals and strategies for Aboriginal cattle enterprises. *Rangeland Journal* **16**: 77-93.

Stafford Smith, M., Ojima, D. & Carter, J. 1997. Integrated approaches to assessing sequestration opportunities for carbon in rangelands. In: *Combatting Global Warming by Combatting Land Degradation* (Eds. Squires, V. & Glenn, E.), UNEP/U.Arizona Press. Pp.305-326.

Buxton, R. and Stafford Smith, M. 1996. Managing drought in Australia's rangelands: four weddings and a funeral. *Rangelands Journal* **18**: 292-308.

Hatch, G.P. and Stafford Smith, D.M. 1997. The bioeconomic implications of various drought management strategies for a communal cattle herd in the semi-arid savanna of KwaZulu-Natal. *African Journal of Range & Forage Science* **14(1)**: 16-24.

Stafford Smith, M., and McKeon, G.M. 1998. Assessing the historical frequency of drought events on grazing properties in Australian rangelands. *Agricultural Systems* **57**: 271-299.

Pickup, G. and Stafford Smith, M. 1999. Management of Arid Lands: a Simulation Approach. In: *Arid Lands Management - Towards Ecological Sustainability* (Eds. Hoekstra, T.W. and Shachak, M.), University of Illinois Press, USA. Pp. 179-193.

Polley, H.W., Morgan, J.A., Campbell, B.D. and Stafford Smith, M. 2000. Crop ecosystem responses to climatic change: Rangelands. In: *Climate Change and Global Crop Productivity* (eds. Reddy, K.R. and Hodges, H.F.), CAB International, UK. Chapter 13, pp.293-314.

Stafford Smith, M., Buxton, R., McKeon, G. and Ash, A. 2000. Seasonal climate forecasting and the management of rangelands: do production benefits translate into enterprise profits? In: *Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems - The Australian Experience* (eds. Hammer, G.L., Nicholls, N. and Mitchell, C.) Atmospheric and Oceanographic Sciences Library, Volume 21, Kluwer Academic Publishers, Dordrecht, ISBN 0-7923-6270-5. Pp.271-289.

McKeon, G.M., Ash, A.J., Hall, W. and Stafford Smith, M. 2000. Simulation of grazing strategies for beef production in north-east Queensland. In: *Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems - The Australian Experience* (eds. Hammer, G.L., Nicholls, N. and Mitchell, C.) Atmospheric and Oceanographic Sciences Library, Volume 21, Kluwer Academic Publishers, Dordrecht, ISBN 0-7923-6270-5. Pp.227-252.

Campbell, B.D., Stafford Smith, D.M., et al. 2000. A synthesis of recent global change research on pasture and rangeland production: reduced uncertainties and their management implications. *Agriculture, Ecosystems and Environment* **82**: 39-55.

Stafford Smith, M. Linking environments, decision-making and policy in handling climatic variability. In: *Beyond Drought in Australia: People, Policy and Perspectives* (Eds. Botterill, L., and Fisher, M.), University of Melbourne Press, Melbourne. pp.131-151.

Dyer, R. and Stafford Smith, M. 2003. Ecological and economic assessment of prescribed burning impacts in semi-arid pastoral lands of northern Australia. *International Journal of Wildland Fire* **12**(3):1-11.

Conference Written Papers, of significant length, with significant refereeing.

Foran, B.D. & Stafford Smith, D.M. 1988 Decisions and dollars - the key to the management of the arid rangelands of Australia. Proc. 3 Intl.Rangel.Conf., New Delhi, India, extended abstract, vol II: 653-655.

Stafford Smith, D.M. & Foran, B.D. 1988 RANGEPACK - microcomputer-based tools to help with decision making in the management of semi-arid rangelands. Proc. 3 Intl.Rangel.Conf., New Delhi, India, extended abstract, vol II: 371-372.

Foran, B.D. & Stafford Smith, D.M. 1990 Getting at risk before it gets at you. Proc.Aust.Rangel.Soc.Conf., Carnarvon, Sept. 1990, pp.142-148.

Stafford Smith, D.M. & Foran, B.D. 1991 Using RANGEPACK Herd-Econ to tackle Australian grazing management questions. Proc.Intl.Conf.on Decision Support Systems for Resource Management, Texas A&M University, College Station, Texas. pp.7-10.

Milham, N., Stafford Smith, M., Douglas, R., Tapp, N., Breen, J., Buxton, R. and McKeon, G. 1995. Farming and the environment: an exercise in eco-economic modelling at the farm level in the NSW rangelands. Invited paper, *Proceedings of the International Congress on Modelling and Simulation*, University of Newcastle, November 1995, **4**: 221–228.

Stafford Smith, M., Milham, N., Douglas, R., Tapp, N., Breen, J., Buxton, R. & McKeon, G. 1995. Whole farm modelling and ecological sustainability: a practical application in the NSW rangelands. Proc.Austr.NZ Soc.Ecological Economics Inaugural Conf., Coffs Harbour, Nov 1995. pp.243-249.

Stafford Smith, M. and McKeon, G.M. 1997. Assessing the historical frequency of drought events on rangelands grazing properties: Case studies. In: *Indicators of Drought Exceptional Circumstances: Proceedings of a Workshop* (Eds. D.H. White and V.M. Bordas). pp.20-24.

Stafford Smith, M., McKeon, G., Buxton, R. and Breen, J. 1999. The integrated impacts of price, policy and productivity changes on land use in northern Australia. In: *People and Rangelands Building the Future* (eds D. Eldridge & D. Freudenberger) *Proc. VI International Rangeland Congress*, Townsville, July 1999. Pp.864-866

Other Sizeable Publications and Reports (>10 pp), lightly refereed

Stafford Smith, D.M. Jan 1988. RANGEPACK HerdEcon: Technical Reference Manual.

Stafford Smith, D.M., Foran, B.D. & Bosman, O. Jan 1988. RANGEPACK HerdEcon: User's Guide.

Soilleux, M. & Stafford Smith, D.M. 1990 RANGEPACK Herd-Econ Version 2: Demonstration Guide. CSIRO, Alice Springs, May 1990. 20 pp.

Stafford Smith, D.M. 1990 RANGEPACK Herd-Econ Version 2: Start Up Guide. CSIRO, Alice Springs, June 1990. 43 pp.

Stafford Smith, D.M. & Foran B.D. 1990 RANGEPACK Herd-Econ Version 2: User's Guide. CSIRO, Alice Springs, June 1990. 260 pp.

Stafford Smith, D.M. & Hope, M.L. (Eds.) 1992. Managing change in North Australian grazing industries. Reports from a RANGEPACK-MRC Training Workshop, Batchelor NT, Aug. 1991. 51 pp.

Stafford Smith, D.M., McNee, A., Rose, B., Snowdon, G., & Carter, C. 1993. Goals and strategies for aboriginal cattle enterprises. Bureau of Resource Sciences, Working Paper 93/.

Stafford Smith, D.M. Aug 1993. RANGEPACK Herd-Econ version 2: Technical Reference Manual. 97 pp.

Buxton, R. Cobon, D., Pastoralists from the region & Stafford Smith, M. 1995. *DroughtPlan Regional Report: Longreach/Richmond, western QLD.* CSIRO Alice Springs, Apr 1995. 20 pp.

Buxton, R. Drysdale, A., Pastoralists from the region & Stafford Smith, M. 1995. *DroughtPlan Regional Report: SW QLD*. CSIRO Alice Springs, Sep 1995. 18 pp.

Buxton, R. Woods, G., Pastoralists from the region & Stafford Smith, M. 1995. *DroughtPlan Regional Report: Western NSW*. CSIRO Alice Springs, Sep 1995. 21 pp.

Buxton, R. Brennan, G., Engleke, J., Jack, E., Pastoralists from the region & Stafford Smith, M. 1995. *DroughtPlan Regional Report: Kimberley*. CSIRO Alice Springs, Jul 1995. 22 pp.

Buxton, R. White, K., Pastoralists from the region & Stafford Smith, M. 1996. *DroughtPlan Regional Report: Gascoyne/Murchison*. CSIRO Alice Springs, Jan 1996. 24 pp.

Buxton, R. Erkelenz, P., Pastoralists from the region & Stafford Smith, M. 1996. *DroughtPlan Regional Report: South Australia*. CSIRO Alice Springs, Jan 1996. 20 pp.

Buxton, R. Crawford, G., Pastoralists from the region & Stafford Smith, M. 1996. *DroughtPlan Regional Report: Central Australia*. CSIRO Alice Springs, Jan 1996. 20 pp.

Stafford Smith, M. & Breen, J. 1995. BB-SAFe Manual. CSIRO Alice Springs, Sep 1995. 26 pp.

Stafford Smith, M., McKeon, G, Ash, A., Buxton, R. and Breen, J. 1996. *Evaluating the use of SOI forecasts in north Queensland using the Herd-Econ/Grasp linked model*. DroughtPlan Working Paper No.**9**, CSIRO Alice Springs.

McKeon, G.M., Stafford Smith, M., Ash, A., Burrows, W.H., Clewett, J.F., Rebgetz, R., Scanlan, R., and Silburn, M. 1997. *Simulation of grazing strategies for beef production in north-eastern Queensland*. DroughtPlan Working Paper No.**8**, Department of Primary Industries, Brisbane.

Stafford Smith, D.M., Clewett, J.F., Moore, A.M., McKeon, G.M. and Clark, R. 1997. *DroughtPlan. Full Project Report*. DroughtPlan Working Paper No **10**, CSIRO Alice Springs/LWRRDC Occasional Paper Series, Canberra. 140pp.

Stafford Smith, M. and McKeon, G.M. 1996. *Assessing the historical frequency of drought events on rangelands grazing properties: case studies*. Report to Bureau of Resource Sciences, Canberra, May 1996. 61 pp.

Cross, J, and Stafford Smith, M. 1999. *Preliminary Analysis of the Effects of Key Tax Instruments on Grazing Enterprises*. RISKHerd Project Report **No. 1**, July 1999. CSIRO, Alice Springs. 41pp.

Stafford Smith, M, Breen, J. and Cross, J. 2001. *The spreadsheet version of Herd Econ: coding, inputs and enterprise descriptions for the RISKHerd and Oceans-to-Farms projects*. RISKHerd Project Report **No.3**/Oceans-to-Farms Project Report **No.2**, CSIRO Alice Springs. 77pp.

Stafford Smith, M., Cross, J. and Breen, J. 2001. *Taxation instruments and grazing enterprises: RISKHerd regional reports*. RISKHerd Project Report **No.6**, CSIRO Alice Springs. 146pp.

Cross, J. and Stafford Smith, M. 2001. *RISKHerd: taxation policy instruments and grazing management in the rangelands*. RISKHerd Project Report **No.8**, CSIRO Alice Springs. 88pp.

Conference Short Written Papers, not usually refereed.

Foran, B.D. & Stafford Smith, D.M. 1988 Helping pastoralists make better decisions. Proc.5th Austr.Rangel.Soc.Conf., Longreach, Qld, extended abstract: 119-122.

Stockwell, T.G.H., Smith, P.C., Stafford Smith, D.M., & Hirst, D. Managing cattle for sustained productivity on native and improved pastures in North Australia. Tropical Grasslands Conference, Toowoomba, Nov. 1990, invited paper.

Hope, M.L., & Stafford Smith, D.M. 1992. Using RANGEPACK Herd-Econ to analyse how sensitive property viability is to managing your biology. NT DPI&F Tech.Bull.200 (Proc.Vet.Tech.Services Seminar, Feb 1992): 19-22

Stafford Smith, D.M. 1994. Planning drought management strategies with a dynamic herd-economic model. Proc.of a workshop on Drought and Decision Support, Mar 1992, Canberra, 52-53.

Stafford Smith, D.M. 1992. Assessing stocking rate strategies in relation to alternative management goals. Proc. 7th Biennial Conf., Austr.Rangel.Soc., Cobar Oct 1992, pp.338-339.

Stafford Smith, M., McKeon, G. & Howden, M. 1994. Global change impacts on rangelands in northern Australia: preliminary results and approaches. 1st GCTE Science Conf., Woods Hole Mass., May 1994: Abstract, pp.37-38.

Stafford Smith, D.M. & Hope, M.L. 1994. Dust and dollars: drought management in Australia. Proc.8th Biennial Conf., Austr.Rangel.Soc., Katherine June 1994, 289-290.

Buxton, R. and Stafford Smith, M. 1996. Managing stock numbers during and after drought. *Proc.Australian Rangelands Society 9th Biennial Conf.*, Sept 1996. pp.60-61.

Stafford Smith, M., Buxton, R., McKeon, G. and Ash, A. 1997. Seasonal climate forecasting and the management of rangelands: do production benefits translate into enterprise profits? *Symposium on Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems: The Australian Experience*, Brisbane, Nov 1997: extended abstract, pp.31-32.

Stafford Smith, Mark, Howden, Mark, McKeon, Greg and Campbell, Bruce. 1999. Informing decision-makers' responses in Australian pastoral systems. GCTE Focus 3 Conference, Reading, UK, Sept 1999. Abstract.

Cross J., Stafford Smith, D.M., and Milham, N. 2000. Do tax instruments support sustainable grazing? *Proceedings of People and Nature: Operationalising Ecological Economics, Sixth Biennial Meeting of the International Society for Ecological Economics*, 5-8 July 2000, Australian National University, Canberra, Australia. International Society for Ecological Economics/Australia and New Zealand Society for Ecological Economics. p.46.

Cross, J. and Stafford Smith, D.M. 2000. Taxation policy instruments and sustainable grazing management in the rangelands. *Australian Rangeland Society Centenary Symposium Papers,* Broken Hill, 21-24 August 2000, (Nicholson, S. and Noble, J. Eds.). Australian Rangeland Society, Broken Hill. pp.225-226.

Other unrefereed short publications, reports, newsletters, etc.

Stafford Smith, D.M., & Donnelly, J. 1989 Decision support tools for Australian agriculture. Ag.Syst.and Info.Tech.Newsl. 1.

Soilleux, M. & Stafford Smith, D.M. 1990 RANGEPACK Herd-Econ Version 2: Demonstration Guide. CSIRO, Alice Springs, May 1990. 20 pp.

Stafford Smith, D.M. 1990 RANGEPACK Herd-Econ Version 2: Start Up Guide. CSIRO, Alice Springs, June 1990. 43 pp.

Stafford Smith, D.M. & Foran B.D. 1990 RANGEPACK Herd-Econ Version 2: User's Guide. CSIRO, Alice Springs, June 1990. 260 pp.

Stafford Smith, D.M. 1990 RANGEPACK Herd-Econ - a dynamic herd and flock model to link the biology and business of a grazing enterprise. Ag.Syst.and Info.Tech.Newsl. 2(2): 9-10.

Stafford Smith, D.M. 1992 Stocking rate strategies across Australia: or, how do you cope with drought ? Range Management Newsletter 92(1): 1-3.

Stafford Smith, D.M., & Hope, M. 1992. Applying RANGEPACK to the management of sheep flocks in the Australian rangelands. Ag.Syst.and Info.Tech.Newsl. 4(1): 19-20.

There was also a series of leaflets on property planning and decision-making in relation to RANGEPACK modules (20 sheets) and DroughtPlan (2).

8. BB-SAFe

- Breed, Buy Sell Agist Feed Evaluator

A. OVERVIEW

Purpose/Objective – whilst it is strategically important to be operating at an appropriate level of stocking to handle climate variability, at some stage producers still face the tactical need to respond to a particular dry period. The major tactics in drought periods involve either reducing numbers or increasing feed availability. They can be catalogued as:

- selling stock;
- agisting stock;
- destroying surplus stock;
- transferring stock to a second property, if this is available;
- feeding stock in a central location (i.e. on-property survival feedlot);
- feeding stock in the paddock with supplements; and
- feeding stock in the paddock with cut feed (e.g. mulga), if available.

Under any scenario, there may be stock deaths above the normal level. After drought, therefore, numbers may need to be re-built, and this may occur by:

- breeding back up; and
- buying stock in.

Keywords – tactical decision making, management of climate variability

Key contact/s –

David Cobon
Department of Primary Industries and Fisheries
203 Tor St, Toowoomba Qld 4350
Email: *david.cobon@dpi.qld.gov.au*
Tel: (07) 4688 1151

Model status – fully developed using 1996 version of Microsoft Excel – unsure of compatibility with existing excel versions

Ownership/Availability – CSIRO, DPI&F, CVAP. Available as part of the DroughtPlan package on CD from DPI&F, PO Box 102, Toowoomba, Qld 4350.

History of development – BB-SAFe is an approach to learning about what costs should be systematically taken into account when comparing drought management tactics. Arising directly from producers' suggestions in late 1994, it was first programmed in Microsoft Excel™. Its design is incremental to enhance learning, and is intended to be applied mainly in workshops where users can be quickly led through the concepts by a facilitator. It is now contained on the DroughtPlan CD.

Documentation –

Stafford Smith, D.M *et al.* (1998). 'DroughtPlan—building on grazier participation to manage for climate variability' by Stafford Smith, D.M., Clewett, J.F., Moore, A.D., McKeon, G.M. and Clark, R., *Occasional Paper CVO1/97. Land and Water Resources Research and Development Corporation*, Canberra. pp. 148.

Cobon, D.H. and Clewett, J.F. (1999). DroughtPlan CD. A compilation of software, workshops, case studies, reports and resource material to help manage climate variability in northern Australia. QZ90002, QDPI, Brisbane.

Links to other models - Nil

Objective assessment – BB-SAFe compares any one of the options in 2 above, or a combined set, against a baseline of doing nothing. Each option has associated costs and benefits, such as the cost of feed or mustering or damage to the environment, and benefits of reduced stock deaths or sale income. These costs and benefits are systematically listed to ensure that decisions are based on all factors rather than an immediate short-term perception. Additionally, the cost of several options (e.g. feeding and agistment) depends on how long the dry period lasts; it is possible to examine alternative periods for this to look at how different options respond to this aspect of climatic uncertainty.

What BB-SAFe does not do: it does not allow for a stepped response to drought, it is still simplified (e.g. approximated build-up calculations, no breakdown of losses by class and age group) as the full complexity can be handled (for considerable extra training investment) by RANGEPACK Herd-Econ. It handles drought as a departure from the normal operation with feeding for survival only (i.e. no changes in stock value through feed-lotting).

B. DETAILED MODEL DESCRIPTION

Model features – programmed in Microsoft Excel™

Model processes – Flock or Herd Management

Minimum data sets required –

Parameter sets –the user chooses an expected drought period, enters the main costs and benefits, and the program then calculates the outcomes. The build-up breed/buy options are handled fully and should be a major focus of exploration in a workshop, so that people understand and accept them. The program automatically selects the cheaper of the two options. The results should be close to those obtained by hand, but can be graphed and subjected to a simple sensitivity analysis.

Similar to above, but introducing the idea of different scenarios by having three possible drought periods—best, worst and medium cases. 2.4 does three sets of 2.3, but allows options-by-scenarios to be plotted and assessed against each other, so the user can see how each option responds to this aspect of risk.

This spreadsheet allows the user to build a combined scenario, for example with some selling, some agisting, some feeding, to calculate a single net cost outcome for this combination. This can be saved for comparison against other combinations.

Development/Validation data –

Sensitivity analyses – sensitivity analysis can be performed

Model output – cost of different tactics and scenarios

Application – assist managers make better financial decisions about adjusting animal numbers

Category 2 - These models are directly relevant to the rangelands but are still under development or recently developed and not in widespread use as yet.

1. agFIRM

- broadacre **Ag**riculture **F**arm **I**ncome **R**isk **M**odel

A. OVERVIEW

Purpose/Objective – in the last ten years the management of climate risk in Australia has progressed from forecasts of cumulative rainfall (Stone et al., 1996) to forecasts of crop (Hammer et al., 1996) and pasture production (Johnston et al. 2000). The agFIRM model seeks to take this transformation in the application of climate forecasting one step further, by enabling seasonal climate forecasting to be applied to the measure of impact most relevant to farmers and policy makers - farm incomes.

Hammer, G.L., Holzworth, D.P., Stone, R., 1996. The value of skill in seasonal forecasting to wheat crop management in a region with high climatic variability. *Australian Journal of Agricultural Research* 47, 717-737.

Johnston, P., Mc Keon, G., Buxton, R., Cobon, D., Day, K., Hall, W., Scanlan, J., 2000. Managing climatic variability in Queensland's grazing lands – new approaches. In G.L. Hammer, N. Nicholls and C. Mitchell (eds), Applications of seasonal climate forecasting in agricultural and natural ecosystems - the Australian experience, Atmospheric and Oceanographic Sciences Library, Vol 21. Kluwer Academic Publishers, Dordrecht.

Stone, R.C., Hammer, G.L., Marcussen, T., 1996. Prediction of global rainfall probabilities using phases of the Southern Oscillation Index. *Nature* 384, 252-255.

Keywords – farm income; pasture growth index; simulated wheat yield; *M*-quantile regression

Key contact/s –

Philip Kokic
ABARE
GPO Box 1563
Canberra, ACT, 2601, Australia.
Email: *Phil.Kokic@abare.gov.au*
Tel: (02) 6272 2063

Rohan Nelson
ABARE
GPO Box 1563
Canberra, ACT, 2601, Australia.
Email: *Rohan.Nelson@abare.gov.au*
Tel: (02) 6272 2017

Model status – the model is still under development. Development is being financially supported by Land and Water Australia (LWA) and internally by the Australian Bureau of Agriculture and Resource Economics (ABARE). In-kind support has been provided by APSRU and QDNRM.

Ownership/Availability – the property rights for the model belong to ABARE. At this stage the model is not available for external clients to use. The main data used by the model: ABARE's farm survey data, is collected from farm operators with the guarantee of nondisclosure to third parties, and hence these data are unavailable to external organisations or clients.

History of development – the basic model development for forecasting incomes began in 1992. This model allowed forecasts to be made conditional on expected commodity prices. In 1996 development began on how to make the model forecast income distributions incorporate the historical uncertainty of yields form ABARE's farm survey data. In 2003 the model was linked to biophysical models of yield, thus enabling forecasts of income distributions conditional on expected climate to be made.

Documentation –

Kokic, P., Beare, S., Topp, V. and Tulpule, V., 1993. Australian broadacre agriculture: Forecasting supply at the farm level. ABARE Research Report 93.7, Canberra, Australia.

Kokic, P., Chambers, R., Beare, S., 2000. Microsimulation of business performance, *International Statistical Review* 68, 259-276.

Kokic, P., Nelson, R., Potgieter, A. and Carter, J., 2004. An enhanced system for predicting farm performance. ABARE eReport 04.6.

Links to other models – the model is linked to QDPI's shire scale wheat yield model (Potgieter et al., 2002) and the AussieGrass model (Carter *et al*., 2000). The output from these two models have been linked by regressions methods to average observed livestock and crop yields from ABARE's farm survey. In general the relationships are very strong. Further details can be found in Kokic *et al*. (2004).

Potgieter, A.B., Hammer, G.L., Butler, D., 2002. Spatial and temporal patterns in Australian wheat yield and their relationship with ENSO. *Australian Journal of Agricultural Research* 53, 77-89.

Carter, J.O., Hall, W.B., Brook, K.D., McKeon, G.M., Day, K.A. and Paull, C.J., 2000. Aussie GRASS: Australian Grassland and Rangeland Assessment by Spatial Simulation. In G.L. Hammer, N. Nicholls and C. Mitchell (eds), 'Applications of seasonal climate forecasting in agricultural and natural ecosystems - the Australian experience'. Atmospheric and Oceanographic Sciences Library, Vol 21. Kluwer Academic Publishers, Dordrecht.

Objective assessment – the strength of the model is that for the first time it enables one to make forecasts of farm incomes conditional on expected climate and expected commodity prices. This measure is potentially more relevant for rural policy makers than just rainfall or crop yields. The model also produces these results at regional level and potentially for different broadacre industries.

The limitation is that the model can only perform conditional climate forecast one year into the future, but this is due more to the corresponding limitation with the biophysical models. More work is also required to extend the model so that it can be used to estimate the probability of farms remaining financially viable. This would be even more relevant for policy makers. Both these developments would require a considerable amount of work to achieve.

B. DETAILED MODEL DESCRIPTION

Model features – the model is coded in SAS, and since it is only for development and testing no specific user interface has been built yet. The model has both spatial and temporal capabilities and its mechanism is time step. The spatial detail is quite coarse, ABARE survey regions, and the time step is financial year. See Kokic et al. (2004) for more details.

Model processes – the model process is farm performance. That is, it uses biophysical measure of crop and pasture yield, expected commodity prices, and an econometric model which predicts farm incomes on the basis of these inputs. The econometric model assumes that the farmer has maximised profit subject to a land area constraint, and then predicts how he/she will adjust production given expected prices and yields in the forecast year.

Minimum data sets required –

- Quarterly averages of the pasture growth index for the 32 ABARE survey regions from 1901 to now.
- Shire level estimates of simulated wheat and sorghum yields from 1901 to now
- A wide range of financial and physical variables from ABARE's annual farm survey from 1979 to now.
- ABS agricultural census data at shire level from the most recent census

Parameter sets –

- Predicted SOI phase in forecast year. Alternatively, specific values of pasture growth and crop yields in the forecast year (this is more appropriate for predicting income based on climate and yields from a previous year).
- With further development and integration effort it should be possible to provide a complete forecast distribution for crop yield and pasture growth which would enable a more accurate forecast to be made.
- Financial year from which forecast is made: this would normally be the current financial year.
- Prices of the major farm commodities: wool, beef, lamb, wheat, other winter crops and summer crops in the base year and the forecast year.

Development/Validation data – validation of agFIRM has not been performed yet, but the data that will be used to validate is ABARE's farm survey data. However, an earlier version of the model has been validated, see Kokic *et al*. (1993).

Sensitivity analyses – the model can be tested for sensitivities to the key regression parameters in the linkage model that predicts crop yields and livestock yields. The model can also be tested for its sensitivity to expected farm commodity prices.

Model output – the key output variable is **farm cash income**. This is defined as total revenue received by the farm during the financial year, less payments made by the farm business for materials, services and hired labour. Other outputs include:

- Total cash receipts
- Total cash costs
- Total production of wool, beef, lamb, wheat, other winter crops and summer crops
- Unit costs of production for each of the commodities above.

Application – model applications are currently under development and so are not described here.

2. SAVANNA.AU

- landscape and regional ecosystem model (Australian version)

A. OVERVIEW

Purpose/Objective – SAVANNA.AU is a spatially explicit, process-oriented model of grassland and savanna ecosystems. It is designed to consider the effects of disturbances such as fire and grazing on the composition of tropical savannas. The detailed plant production processes allow the model to determine species compositional changes with disturbance.

Keywords – Vegetation, fire, pastoralism, primary production, soil water, management

Key contact/s –

Adam Liedloff
Tropical Savannas Management CRC and CSIRO Sustainable Ecosystems
CSIRO Tropical Ecosystems Research Centre
PMB 44, Winnellie, Northern Territory, 0822
Email: *adam.liedloff@csiro.au*
Tel: (08) 8944 8446

John Ludwig
CSIRO Sustainable Ecosystems
Email: *john.ludwig@csiro.au*

Michael Coughenour
Colorado State University
Colorado, USA

Model status – the Savanna (original) model has been developed and widely used and was parameterised for Australian savannas (Kidman Springs, NT, M. Coughenour, 1998). Savanna.au is a re-developed version of this model with modern coding to allow greater flexibility, simplified parameterisation, and incorporates a range of additional functions considered important for modelling Australian tropical savannas. This version of the model is currently under development by the Tropical Savannas Management CRC (TSM CRC) and CSIRO Sustainable Ecosystems (CSE) and is now being used for initial validation simulations.

Ownership/Availability – IP for SAVANNA.AU is divided between TSM CRC and Mike Coughenour (Colorado State University). The current model code and user interface has been developed by TSM CRC with particular model components, development and underlying processes developed by Mike Coughenour and other acknowledged participants. The model is available in collaboration with the developers and has not been released for general use.

History of development – SAVANNA.AU development commenced in 2001 and the model is now being implemented into a range of TSM CRC and other projects. The model is currently a research tool and can be used in collaboration with the developers to investigate tree dynamics in tropical savannas.

Documentation – a full model description, manual and users guide is available.

Links to other models – The SAVANNA.AU model incorporates the plant primary production, light interception, and plant water budget components of the Savanna model.

Objective assessment – being a mechanistic model, Savanna.au does require an amount of parameterisation and prior knowledge before any simulation can be performed. This is a trade-off between simplistic models and those with mechanistic detail. Savanna.au allows detailed simulations to be performed looking at specific areas of plant growth, competition, grazing and eco-hydrology. Savanna.au has also added to the level of detail offered by Savanna, by running on a daily time step that was considered important to realistically simulate eco-hydrological processes.

B. DETAILED MODEL DESCRIPTION

Model features –

Style and time-step

SAVANNA.AU is a process based, mechanistic model designed to simulate a single plot of trees (point based, default hectare) or a contiguous group of cells to represent a landscape (up to paddock or hillslope scale) with hydrological processes (runon and runoff) simulated between cells. The model runs on a daily time step.

Spatial and Temporal capability

SAVANNA.AU is designed to simulate a single cell (hectare plot), but has the ability to simulate contiguous cells. While there is no limit to the number of cells which can be simulated, the model is only expected to simulate a paddock or hillslope (20x20 hectares). In terms of computation for large scale areas, we suggest that single representative cells be simulated and extrapolated to the landscape scale.

Language and Interface

The SAVANNA.AU model is written in Microsoft Visual C++ (V6.0) and distributed as an ActiveX Control and also as a model executable (.EXE).

The user interface (MYME – My Modelling Environment, Liedloff, 2004) is written in Microsoft Visual Basic (v6.0). The user interface controls all parameter entry, parameter checking prior to running the model, data management, error and warning handling and output control.

Model processes – plant growth, plant competition, plant composition, plant water use, plant mortality, decomposition, nutrients, soil hydrology, infiltration, fuel, litter dynamics, grazing, fire frequency, fire intensity.

Minimum data sets required –

- Daily rainfall files as obtained from Bureau of Meteorology (BOM) or SILO
- Average monthly 9 am and 3 pm temperature, humidity and mean and standard deviation wind speed from BOM for fire intensity
- Land unit for each cell simulated – tied to soil descriptions
- DEM of cells to provide run-off run-on capabilities with sink holes removed.
- Physical parameters for each plant functional group.

Parameter sets – all parameters can be accessed and set by the user, as no values are hard coded into the model. This provides a large number of parameters, but equally makes the model extremely dynamic and controllable. A key set of parameters is required to initialise the model and provide management scenarios.

Fire

Fire regime, frequency, timing (month, am/pm), type (elliptical or fronting), minimum curing rates

Soil

Rooting depths

Textural information (% sand, silt, clay) or Bulk density and Particle density

Plant parameters (multiple species can be used)

Climate

Breakdown of daily rainfall into two events

Development/Validation data – see sensitivity analyses

Sensitivity analyses – validation and sensitivity analysis is currently being undertaken to produce a SAVANNA.AU publication.

Model output – a large range of values can be generated by the model in Tab delimited ASCII files for easy importing into Excel or sent directly to Excel from the user interface.

Spatial output maps are also available to animate simulated changes over the duration of the simulation

Application – current and future uses of the SAVANNA.AU model include:

- Eco-hydrology simulations for hillslope run-off
- Preferential cattle grazing
- Parameterisation for South African fire trials
- Invasion and management of woody and grassy weeds

3. CCE - Carrying Capacity Evaluator

- assessing the long-term carrying capacity in south-west Queensland

A. OVERVIEW

Purpose/Objective – CCE is a community-owned approach to assessing safe long-term carrying capacities, pioneered in south-west Queensland.

The vegetation of south-west Queensland is composed of annual grasses and forbs, perennial grasses and shrubs, and trees. Their structure and composition is determined by rainfall, grazing pressure, frequency of fire, soil type and topography. Due to the high degree of rainfall variability (seasonal incidence, amount and reliability), the structure and composition of the vegetation varies from place to place and from year to year. Managing grazing animals in an environment characterised by such variability is difficult and requires skill.

The carrying capacity is based on estimates of the potential average annual forage growth (kg/ha) for each land system on a property. These estimates are the product of average annual rainfall use efficiencies for each land system and the long term average rainfall for that property. Actual forage growth is then estimated after accounting for the negative effect of tree and shrub cover. An estimate of the number of livestock which would utilise the ‘safe’ portion of the actual forage growth is then calculated. The level of ‘safe’ utilisation is based on utilisation levels measured in grazing trials conducted in south-west Queensland and on estimated utilisation levels calculated on five benchmark properties. Summing the livestock numbers across the land systems on a property produces an estimate of a ‘safe’ long term carrying capacity for that property. The term ‘safe’ implies conservative levels of forage utilisation by domestic livestock and consequent sustainable resource use (based on previous research).

Keywords – safe carrying capacity, south west Qld, mulga

Key contact/s –

David Cobon
Department of Primary Industries and Fisheries
203 Tor St, Toowoomba Qld 4350
Email: *david.cobon@dpi.qld.gov.au*
Tel: (07) 4688 1151

Peter Johnston, Department of Primary Industries and Fisheries, Brisbane

Model status – the model is operational in SWQ and some modifications have been made for other pasture communities. The model is developed and is currently available to the public on the DroughtPlan (suite of DSS) including BBSAfe

Ownership/Availability – Queensland DPI&F, National Landcare Program, Southwest Strategy, SWQ landholders. Available as part of the Droughtplan package on CD from DPI&F, PO Box 102, Toowoomba, Qld 4350.

History of development – see

Johnston, P.W., McKeon, G.M. and Day, K.A. (1996). Objective safe carrying capacities for south-west Queensland Australia: Development of a model for individual properties. *Rangeland Journal* **18**: 244-58.

Documentation -

Johnston, P.W., McKeon, G.M. and Day, K.A. (1996). Objective safe carrying capacities for south-west Queensland Australia: Development of a model for individual properties. *Rangeland Journal* **18**: 244-58.

Stafford Smith, D.M et al (1998). 'DroughtPlan—building on grazier participation to manage for climate variability' by Stafford Smith, D.M., Clewett, J.F., Moore, A.D., McKeon, G.M. and Clark, R., Occasional Paper CVO1/97. Land and Water Resources Research and Development Corporation, Canberra pp 148

Cobon, D.H. and Clewett, J.F. (1999). DroughtPlan CD. A compilation of software, workshops, case studies, reports and resource material to help manage climate variability in northern Australia. QZ90002, QDPI, Brisbane.

Links to other models – Nil

Objective assessment – There are a number of methods by which the mathematical relationships can be implemented to calculate a 'safe' carrying capacity for a property. However, the Calculator is only one step in the assessment of a property's carrying capacity. Detailed maps of the property and surveys of land condition are required before the Calculator can be used. As a result, the Calculator is ***not*** a stand-alone product. Access to maps of land types and some knowledge of techniques for conducting land condition surveys are essential. Once this information has been obtained then the Calculator can be used.

B. DETAILED MODEL DESCRIPTION

Model features – Visual basic, empirical

Model processes – plant growth,

Minimum data sets required – Nil

Parameter sets –

- Inputs ground cover, scrub cover, land types
- Hardwire RUE for different land types, utilisation, animal intakes

Development/Validation data – see Johnston *et al.* (1996)

Sensitivity analyses – see Johnston *et al.* (1996)

Model output –carrying capacity for individual paddocks

Application –

The model provides an objective estimate of 'safe' long term carrying capacities for individual paddocks and properties based on ecological principles and previous research. It also provides;

- Tools for objectively examining grazing resource capability from a financial and physical management perspective (i.e. a starting point for property management planning and risk management concepts) which does not rely on many years of local experience.
- Additional support for appreciating grazing resource capability and climatic variability.
- Recognition that each paddock and property has a unique combination of land systems in various conditions producing a unique carrying capacity. This avoids the use of 'district average' carrying capacities with potentially misleading results.

- A repeatable method for estimating ‘safe’ carrying capacities enabling application to any property or region where appropriate data is available. It may also be applied to the one paddock, property or region over time to examine the impact of changes in resource condition through development or degradation.

4. CENW-TG

- a spatially explicit tree/grass ecosystem model for climate change studies.

A. OVERVIEW

Purpose/Objective – CENW-TG is being developed to address the issue of tree/grass ecosystem response to changes in atmospheric CO_2, temperature, rainfall, and fire and grazing regimes at the stand scale. The approach underlying the model is to produce a tool which could not only be used to simulate ecosystem response to climate change, but also, and more importantly, to explore the mechanisms leading to that response, and to compare the relative importance of the numerous processes involved in ecosystem dynamics linked to carbon budget. CENW-TG is therefore heavily mechanistic and incorporates a large number of processes.

Keywords – spatial patterns, radiation transfer, individual-based model, water balance, tree/grass interactions, spatially explicit model, demography, climate change, fire, herbivory, carbon budget, nitrogen

Key contact/s –

Guillaume Simioni
CSIRO Forestry and Forest Products, PO Box E4008, Kingston ACT 2604
Email: *guillaume.simioni@csiro.au*
Tel. (02) 6281 8406
Fax. (02) 6281 8312

Miko UF Kirschbaum
CSIRO Forestry and Forest Products
Email: *miko.kirschbaum@csiro.au*

Model status – the model is in its final stage of development. The development is supported by the CRC Greenhouse Accounting.

Ownership/Availability – the model can be made available after contacting the developers.

History of development – model development started in 2002.

Documentation – no document is available at this point. A model description report should be released by June 2004, while a paper presenting the first model tests should be submitted by late June 2004.

Links to other models – CENW-TG incorporates some of the features of the CENW forest growth model (Kirschbaum, 1999. *Ecol. Model*. 118:17-59); CENW-TG is incorporated in the landscape modelling shell LAMOS (developed at the ANU, Canberra). It is, though, an ecosystem, not a landscape, model.

Objective assessment –

Strengths

The comprehensiveness of the model makes it very powerful to explore the mechanisms driving ecosystem behaviour. By incorporating the many feedbacks potentially important in the context of climate change, the model allows study of the integrated response of an ecosystem.

Limitations

The comprehensiveness of CENW-TG means that it requires large datasets in order to be parameterised and tested.

B. DETAILED MODEL DESCRIPTION

Model features –

- coded in Delphi 7;
- complete, personalised user interface within LAMOS;
- Mechanistic;
- spatially explicit (similar structure to that of the gap model, with an additional foliage clumping factor within pixels);
- Runs at a daily timestep for periods of a few years to several centuries;
- Multi-species, with many species attributes: annual/perennial grasses, evergreen/deciduous trees, C3/C4 photosynthesis;
- Individual based;

Model processes –

Within pixels:

- Full C, N, and water cycles;
- Plant competition for light, water, and nitrogen;
- Plant physiology (photosynthesis, transpiration, allocation, senescence, …);
- Plant demography: mortality, seed dormancy and germination;
- Soil organic matter decomposition;
- Soil water balance;
- Fire and grazing effects on C and N stocks and on plants;

Between pixels:

- seed dispersal

Minimum data sets required –

- Input climate variables: daily radiation, min/max temperature, rainfall, eventually air humidity;
- Data to initialise the model (if run for a real site, i.e. model test): tree layer structure, species composition, soil water contents …

Parameter sets – predicted trends are heavily dependent on model parameterisation. An appropriate parameterisation is therefore paramount:

- Site latitude;
- Species attributes: photosynthetic capacity, stomatal conductance, tree allometry, organ senescence rates, organ N concentrations, leaf properties, demography, sensitivity to fire, sensitivity to water stress, water extraction pattern, phenology;
- Field capacities and wilting points for the relevant soil layers;
- Soil clay content;
- Fire regime (specify dates or time lapse between fire events);
- Grazing pressure;

Development/Validation data – the model is currently being parameterised and tested for the Howard Springs site (Darwin), using a comprehensive datasets ranging from leaf gas exchange measurements to ecosystem C and water fluxes measured by a flux tower.

Sensitivity analyses – none yet.

Model output –

- Too much to list and all outputs are customisable, but include:
- Number of species and plants in each pixel;
- Height and DBH of the tallest plant of each species in each pixel;

- Light absorbed by each species in each pixel;
- C and N content for all organs for each species in each pixel;
- Transpiration by each species in each pixel;
- C and N soil carbon pools in each pixel;
- Soil evaporation, runoff, and drainage in each pixel;
- Soil water content for each soil layer in each pixel;
- Amount of C and N loss to fire and grazing in each pixel;

Application – the model hasn't been used yet, but simulations planned include the response of net ecosystem C exchange to various scenarios of climate change and burning and grazing regimes, for at least two contrasted savanna types in Australia.

5. CSP version 2.0

– carbon sequestration predictor

A. OVERVIEW

Purpose/Objective – the CSP has been developed as part of the NSW Environmental Services Scheme, which aims to promote land use and land management changes, based on an assessment of the off-farm environmental benefits likely to be delivered. The CSP, and other tools, have been developed to quantify the environmental impacts of changes in land management.

The CSP predicts the likely changes in both biomass and soil carbon in association with a number of land use changes. The principal focus is on changes from annual herbaceous (crops and pastures) to perennial woody vegetation (commercial and environmental tree plantings) in regions of NSW with less than 800mm rainfall. Predictions are given for 10 and 40 year time periods.

Keywords – carbon, sequestration, biomass, soil carbon, land use, land management

Key contact/s –

Kelvin Montagu
Research and development Division
State Forests of NSW
PO Box 100, Beecroft, NSW 2119

Model status – Fully operational.

Ownership/Availability – State Forests of NSW

History of development – see 2 above

Documentation –

Montagu, K.D., Cowie, A., Rawson, A., Wilson, B.R. and George, B.H. (2003) Carbon Sequestration Predictor for land use change in inland areas of New South Wales – background, user notes, assumptions and preliminary model testing, version 2.0. *Technical Paper No. 68*. Research and Development Division, State Forests of NSW. 44pp.

Links to other models – CSP has been incorporated into the Strategic Landscape Investment Model (SLIM, Hajkowicz *et al.*, 2003)

Hajkowicz,S., Perraud, J., De-Rosa, R, Austin, J. and Dawes, W. (2003) The Strategic Landscape Investment Model. Final Report for NSW Department of Sustainable natural Resources, CSIRO and NSW land and Water Conservation.

Objective assessment –

Strengths

- Simple and easy to use

Weaknesses

- Model functions are based on a limited set of data, particularly for the <800mm rainfall region
- Almost all tree data based on stands <10 years old
- Soil response based on agricultural fertility rankings and may not reflect suitability for tree growth

- Assumes all tree plantings were successful
- There is no management interception e.g. thinning, harvesting

B. DETAILED MODEL DESCRIPTION

Model features – the user interface is via pull down menus. The model is point based in a landscape context, driven by empirical relationships.

Model processes – the model predicts plant biomass carbon by selecting 1 of 8 curves (of the form of Richards growth curve), depending on the land use, rainfall and site modifier. Above/below ground partitioning is based on an age constant root:shoot ratio. Soil Carbon (SC) is based on a 4-step process where the soil carbon stock for the rainfall region is obtained from a look-up table, then adjusted for current land use. Similarly, the SC stock under proposed land use is determined, and the rate of change from current to proposed values is implemented by selection of one of 5 change curves.

Minimum data sets required – no external data sets are required

Parameter sets –

- current land use - cropping, annual pasture, poor perennial pasture or degraded native vegetation
- proposed land use (for ESS activity) - commercial planting, environmental planting, managed for regeneration, saltbush or perennial pasture
- soil type – 13 soil types available, as per Australian Soil Classification system
- rainfall – 4 categories (<400, 4-600, 6-800, >800mm) long-term average rainfall
- site modifier for local conditions – none, salt affected, non-saline water table, lower slope

Development/Validation data – above ground biomass has been benchmarked against some recent measurements. Predictions were unbiased with model predictions ranging from 86-160% of estimated values, depending on whether trees were slow or fast growing.

Sensitivity analyses – none described

Model output – the model gives a table indicating changes in soil organic carbon, above and below ground plant biomass carbon and total carbon after 10 years, and presents a graph of changes in the same attributes over 40 years

Application –

CSP predicts likely changes in both biomass (trees, shrubs and grasses) and soil carbon associated with changes in land use. CSP aims to inform landholders, policymakers and the public on the potential for carbon to be sequestered by land use changes in the lower rainfall areas (<800mm) of NSW.

CSP has been used by the NSW Environmental Services Scheme and incorporated into the Strategic Landscape Investment Model, to inform resource allocation so that resource funding to support land use change is directed to maximise environmental benefit (Hajkowicz *et al*. 2003).

6. ENTERPRISE
- a rangeland enterprise pasture-herd dynamics-economics model

A. OVERVIEW

Purpose/Objective – this Excel spreadsheet model mimics the production and economic outcomes of rangeland enterprises subject to a range of management strategies (stocking rate, stocking strategy, seasonal forecasts etc) and the climatic variability experienced over many years. It links climate and pasture growth (via GRASP) to herd dynamics and economic outcomes. The economic outcome for a given year in the simulation run is assessed using a whole-enterprise budgeting technique that tries to accurately represent all the costs of a grazing enterprise and provides estimates of total gross margin and return on capital and management (net profit) for an array of equity levels.

Keywords – economics, enterprise, herd dynamics, climate variability, pasture growth, stocking rate, stocking strategy

Key contact/s –

Neil MacLeod
CSIRO Sustainable Ecosystems
306 Carmody Rd
St Lucia
QLD 4067
Email: *Neil.MacLeod@csiro.au*
Tel: (07) 3214 2270

Andrew Ash
CSIRO Sustainable Ecosystems
306 Carmody Rd
St Lucia
QLD 4067
Email: *Andrew.Ash@csiro.au*
Tel: (07) 3214 2346

Model status – the model was developed in 2001 and has been applied in assessing the value of different stocking strategies and use of seasonal forecasts. The user-interface is currently being redesigned as part of a CSIRO Water for a Healthy Country project, to enable the model to be applied more widely to assess trade-offs between different grazing management strategies, economic performance and soil loss. For the linked GRASP model see model status for GRASP.

Ownership/Availability – the model is available based on one-to-one negotiation. The current version is owned by CSIRO.

History of development –

1996-1998 – A simple static (steady state) enterprise economics model was developed for concurrently exploring up to 3 different management scenarios. This first model assumed a static enterprise in which a number of different management scenarios could be explored "averaged" over a sequence of years i.e. the interannual variation in climate and pasture growth and its impact on herd dynamics was not captured (see MacLeod et al. 2004 in publications list).

1998-2001 – A "dynamic" variant of the herd model was developed by capturing inter-annual variation in pasture growth and liveweight gain through a linkage to output from the GRASP model (see MacLeod and Ash 2001). This model was still restricted to concurrently exploring up to 3 management scenarios.

2003- Improvements underway to make the user interface in Excel more “friendly” and to remove the limitation of three management scenarios.

Documentation –

MacLeod, N. and Ash, A. 2001. *Development of a spreadsheet herd dynamics model to assess the economic value of forecasts in extensive grazing enterprises*. Oceans to Farms Project Report No.6, CSIRO Sustainable Ecosystems, Brisbane and Townsville. 11 pp.

MacLeod, N.D., Ash, A.J. and McIvor, J.G. (2004) an economic assessment of the impact of grazing land condition on livestock performance in tropical woodlands. *The Rangeland Journal* 26, (in press)

Links to other models – ENTERPRISE is currently dependent on output from GRASP, which provides the input parameters for ENTERPRISE for annual stocking rate and liveweight gain. The conceptual basis of this linked GRASP-herd dynamics model is closely linked to GRASP-HerdEcon, the main difference being in the structure of the ENTERPRISE model (i.e. relatively simple Excel spreadsheet versus Visual C for HerdEcon although a spreadsheet version of HerdEcon has now been developed as part of the RISKHERD project), and in its aim to capture in some detail the various costs associated with running case study enterprises.

Objective assessment – ENTERPRISE’s strengths are in its transparent approach to modelling herd dynamics and enterprise economics. All the formula and equations can be viewed, so the whole modelling process can be tracked. The parameters required to “set up” an enterprise are quite detailed, but most can be readily supplied by reasonably astute producers.

The biggest weakness of ENTERPRISE is the link between liveweight gain and reproduction, branding and mortality. While it is known that the drivers of reproductive performance are far more complex than simply derived relationships from liveweight gain, a sufficient mechanistic understanding is still not available to model this any better than through liveweight gain. The interface in the current spreadsheet version is quite complex, but this issue is currently being addressed.

B. DETAILED MODEL DESCRIPTION

Model features – the model has been built on a platform of two linked Microsoft Excel spreadsheet files, both of which are comprised of a number of specialised worksheets. The first spreadsheet file contains the input cells and formulae to parameterise the herd model for a single year of a simulation run, including various selling, feeding and herd management rules. This includes, for example, target market weights for finished stock, culling rules for dry breeders, minimum retention rates for maiden heifers and various selling down rules for forced sales in the event of dry seasons. The file calculates a range of production, revenue, cost and profit measures for the year iteration for each of the (maximum) 3 herd management strategies that can be set for the model.

The second spreadsheet file contains 100-year sequences of data output derived from the GRASP model – liveweight gain, mortality and branding rates, feeding days. These estimates are also provided for the (maximum) 3 herd management strategies along with annual target sizes for the breeder and steer herds. This file also includes a running total of the number of livestock of different categories (e.g. calves, bulls, yearling steers etc) on hand in each year of the simulation run, along with sales and purchases for that year based on the numbers on hand, target numbers, season type and selling/feeding rules. The numbers of animals in each year (t) are linked to those on hand after sales, purchases, mortality and breeding success of the year before (t-1) have been accounted for. Sales and purchases are set against the target numbers of breeders and steers in a given year of the simulation run. Data for each year of the 100 year sequence is linked between the two files via the “Tools -What If” facility of Excel.

Model processes – model processes include forage production and utilisation which drive steer liveweight gain over a sequence of years (this is accomplished within GRASP, Littleboy and McKeon 1997) although the liveweight gain functions change according to land condition (Ash et al. 1995). Liveweight gain is used to drive reproduction, branding, mortality rates and the amount of supplementary feeding required in the spreadsheet herd dynamics module. Economic performance is derived from total gross margin, net profit and return on capital.

Ash, A.J., McIvor, J.G., Corfield, J.P., and Winter, W.H. (1995). How land condition alters plant-animal relationships in Australia’s tropical rangelands*. Agriculture, Ecosystems and Environment* **56**: 77-92.

Littleboy, M., and G.M. McKeon, (1997). Subroutine GRASP - Grass Production Model, Appendix 2, *Final Report DAQ-124A Evaluating The Risks Of Pasture And Land Degradation In Native Pastures In Queensland*. Queensland Department of Primary Industries, Brisbane.

Minimum data sets required – for the GRASP component: (1) daily climate data – rainfall, maximum temperature, solar radiation, pan evaporation, vapour pressure; (2) site characteristics include tree basal area; (3) stocking rate and stocking strategy (4) soil water holding capacity; (5) fertility as represented by peak nitrogen uptake; (6) temperature response of the sward. Average parameter sets have been developed for different pasture communities.

The only key data the herd economics spreadsheet requires is some basic property characteristics, the rest are largely parameters that are varied according to particular applications.

Parameter sets –

For GRASP model (see GRASP listing)

For the Economics spreadsheet:

- sale prices for various classes of livestock
- costs associated with running the enterprise, including: labour, supplementary feeding costs, transport, sales commission, chemicals and vet care etc.
- other financial parameters to derive net profit include capital costs for depreciation, level of debt and interest rates.

Development/Validation data – collaborative case studies with producers has shown that the outputs are sensible and the gross margins are consistent with regional trends during cycles of drought, good seasons, and low and high prices. The weakest link in the model is the derivation of branding and mortality rates from liveweight gain data and it is recognised that these relationships are based on inadequate data sets.

Sensitivity analyses – sensitivity studies have been carried out as a development, however they have not been reported in any citeable document.

Model output – outputs include: (1) gross margin (2) net profit (3) return on capital (4) variability in economic returns (5) land condition (6) soil loss.

Application – the model has been used to assess the economic viability of different grazing management strategies in relationship to grazing system and land condition (Ash *et al.* 2001a; MacLeod *et al.* 2004). It has also been used to assess the economic value of different seasonal climate forecasts (Ash *et al*. 2001b) and is currently being refined to assess the ecological-economic trade-offs of different management strategies to meet NRM targets in NAP regions.

Ash, A.J, Corfield, J.P. and Ksiksi, T. (2001a) *The Ecograze Project: developing guidelines to better manage grazing country*. CSIRO, Townsville, 44pp.

Ash, A.J., MacLeod, N.D., Stafford Smith, M., McDonald, C.K. and McIntosh, P. (2001b). Evaluation of Seasonal Climate Forecasts for the Extensive Grazing Industry in North-East Queensland. Oceans to Farms Project Report No.8, CSIRO Sustainable Ecosystems, Townsville. 13 pp.

MacLeod, N.D., Ash, A.J. and McIvor, J.G. (2004) An economic assessment of the impact of grazing land condition on livestock performance in tropical woodlands. *The Rangeland Journal* 26, (in press)

7. Golden Wing GRASP

- Tree Growth and Establishment Model for Australia's Open Woodlands

A. OVERVIEW

Purpose/Objective – Golden Wing is a 'tree growth' model which simulates the population and mass dynamics of the woody component of open woodland communities of Australia. The model has been tested across a wider range of communities from rainforest to near-desert communities. The model has been developed with the GRASP soil water and pasture production model and is run as a sub-routine in various versions of the GRASP model. Thus, the Golden Wing tree model provides a dynamic woody vegetation layer to the GRASP pasture growth model. The model is used to simulate changes in dry matter mass of open woodland communities with different grazing management options and under different climate change scenarios. Model applications are the same as indicated for GRASP.

Keywords – tree growth, carbon dynamics, tree microclimate, soil water, pasture growth, drought and degradation risk, climate risk assessment, seasonal climate forecasting, safe carrying capacity, grazing land management

Key contact/s –

John Carter
Department of Natural Resources, Mines and Energy
Email: *john.carter@nrme.qld.gov.au*
Tel: (07) 3896 9588

Chris Chilcott – simulation application to GLM
Dorine Bruget – supercomputer coding
Rob Hassett – field validation

Model status – the model is still in the developmental stage with both model development and validation occurring. Components of the model have been used in major simulation studies with regard to the impact of climate change.

Ownership/Availability – the model is available as a sub-routine based on one-to-one negotiation. The current version is owned by NRM&E.

History of development –

- 1996 – Greg Dupont conducted extensive field studies from which relationships on the effect of tree density on tree microclimate were developed;
- 1997 – the first version was developed to simulate population and mass dynamics of *Acacia nilotica* in the Mitchell Grasslands;
- 2000 – the model was further tested and developed for a series of sites ranging from rainforest to desert communities;
- 2004 – a tree establishment model was developed and tested with simulation studies;
- 2004 – a workshop was conducted in which the model was reviewed and compared to other woody vegetation models.

Documentation –

Carter, J.O., McKeon G.M., and Bruget, D. (2004). Golden Wing Tree Growth and Establishment Model for Australia's Open Woodlands, Version 1.1.

Dupont, G.V. (1997) *The effects of trees on microclimate along a rainfall gradient in south-Queensland*. Masters of Agricultural Science Thesis, Department of Botany, University of Queensland.

Links to other models – the model has been linked to GRASP (see GRASP model description, this document) and has been used in AussieGRASS (see AussieGRASS description, this document).

Objective assessment – the strengths of the Golden Wing tree model are: (1) its direct incorporation in the GRASP soil water pasture-growth model; (2) its treatment of the impact of dynamic tree density on tree microclimate; (3) the continental basis for parameterisation including hundred year simulation testing; and (4) its parameterisation and testing from extensive rangeland and open woodland sites across Australia.

The weaknesses of the Golden Wing tree model are: (1) the model does not represent cohorts or individual trees; (2) data on soil water and dry matter flows are very limited and hence parameterisation is based on a limited dataset; and (3) the processes of plant growth and senescence for the major woody species of Australia's open woodlands are not fully understood.

The limitations of the model are: (1) the model does not include a full carbon and nitrogen cycle; (2) the model does not include responses to applied fertility such as phosphorus; and (3) the responses of individual species to CO_2 and temperature change are not known.

B. DETAILED MODEL DESCRIPTION

Model features – the model is written in FORTRAN; a version suitable for running on supercomputers has also been developed. The model is unabashedly empirical with a daily time-step. The model represents a point, i.e. no explicit spatial or grid modelling occurs. Thus, the model represents a stand of trees but not individual trees.

Model processes – in conjunction with GRASP, the model processes include a full soil water balance with soil evaporation, tree and grass transpiration, runoff and drainage. Tree growth is calculated from radiation interception, transpiration or regrowth from tree basal area. Growth is regulated by soil water, solar radiation, vapour pressure deficit, temperature and nitrogen. Canopy cover is fully dynamic. Herbivory, fire and detachment remove dry matter. Trees compete with pasture for nitrogen and water. Sub-models of germination, establishment, growth, reproduction, death and seedling herbivory are included. Growth is partitioned between roots, leaves, fruit and wood. Components of carbon and nitrogen cycles are simulated. Population dynamics such as self-thinning are included. Fire, harvesting and grazing management effects are included.

Minimum data sets required – as for GRASP: (1) daily climate data – rainfall, maximum temperature, solar radiation, pan evaporation, vapour pressure; (2) site characteristics include tree basal area; (3) stocking rate of sheep or cattle; (4) soil water holding capacity; (5) fertility as represented by peak nitrogen uptake; (6) temperature response of the stand. Average parameter sets have been developed for an average tree community. Specific parameter sets are available for *Acacia nilotica.*

Parameter sets – the same general procedure used in GRASP has been used for tree growth parameters:

- Radiation use efficiency
- Transpiration use efficiency
- 4 temperatures describing a ramp function for growth
- Frost starting and frost killing temperature
- Potential rate of regrowth from tree basal area following defoliation
- Soil water index leading to wood death

- Soil water index leading to enhanced loss of tree leaf
- Green biomass that gives 1% foliage projective cover
- Leaf detachment rates
- Maximum nitrogen uptake
- Maximum and minimum nitrogen concentrations (wood, roots, leaf, reproductive material)

In addition, tree related parameter sets are required for: (1) germination; (2) herbivory; (3) death and regrowth (seedling and small trees); (4) nitrogen of leaf, wood, roots and fruits; (5) death of large trees; (6) decay of woody debris and dead tree biomass falling; and (7) partitioning related to dry matter pools.

Development/Validation data – this has come from a number of sources: (1) a literature review of models such as 3PG (Landsberg and Waring 1997); (2) basic information on tree growth (Eastham and Rose 1990, Calder 1992); (3) monitoring sites on *Acacia nilotica* (J.O. Carter unpublished data); (4) TRAPS monitoring sites for woody vegetation in Queensland (Burrows *et al*. 2000); (5) tree establishment sites (Crimp *et al.* 2004); (6) tree basal area and foliage projective cover at sites across Queensland; and (7) forest growth (as published in Landsberg and Waring 1997).

Sensitivity analyses – sensitivity studies have not yet been carried out. Calibration is manual or by genetic algorithm.

Model output – outputs include: (1) tree stand dynamics in terms of tree basal area; (2) foliage projected cover; (3) tree height; (4) biomass components of the stand including standing live and dead wood, live and dead roots, old and new leaves, course woody debris, green fruit, mass of ripe seed on tree and ground; and (5) available tree nitrogen for growth is also calculated. In addition, the outputs from GRASP including components of the soil water balance, tree microclimate and pasture growth are calculated.

Application – although the model is in development, the following applications have been conducted: (1) historical dynamics of *Acacia nilotica* in Mitchell grasslands; (2) rehabilitation of grass and woody vegetation at Osborne Mile; and (3) the effect of climate variability and change on the establishment of trees and seedlings on commercial and revegetation plantings.

Carter, J.O. (2002) Climate variability and the invasion of the exotic tree *Acacia nilotica* into Mitchell grasslands of northern Queensland. In proceedings Prickly Acacia Workshop October 2002 Alan Fletcher Research Station, Sherwood Qld.

Morrison, B. (2003) *Long-term Sustainability of Rehabilitation at Osborne Mine, Northwest Queensland.* Honours thesis, Department of Botany, University of Queensland.

O'Connell, D., Crimp, S., McIvor, J., Graham, S., Carter, J., Howden, M., Carr, D. (2004). *Enhancing Natural Resource Management By Incorporating Climate Variability Into Tree Establishment Decisions*. Report for Land & Water Australia, Climate Variability in Agriculture Program, March 2004.

8. GrazeOn

- feed budgeting for Mitchell grass pastures in Qld

A. OVERVIEW

Purpose/Objective – GrazeOn is designed to calculate short-term (3-12 months) stocking rates bases on total standing dry matter, at the end of the summer growing season. This model calculates tactical short-term stocking rates using objective data on pasture biomass pasture condition, pasture defoliation, grazing by kangaroos, animal intake and simple spatial aspects of grazing management.

Keywords – Grazing, Mitchell grass, stocking rate, responsive grazing

Key contact –

David Cobon
Department of Primary Industries and Fisheries
203 Tor St, Toowoomba Qld 4350
Email: *david.cobon@dpi.qld.gov.au*
Tel: (07) 4688 1151

Model status – the model developed and is currently available to the public on the DroughtPlan CD (suite of DSS) including BBSAfe and Carrying capacity evaluator.

Ownership/Availability – Ownership of GrazeOn is with DPI&F and NLP. Available as part of the Droughtplan package on CD from DPI&F, PO Box 102, Toowoomba, Qld 4350.

History of development – Model was developed between 1994 and 1996. David Cobon and Greg Pinington were the key developers.

Documentation –

Cobon, D.H. and Pinington, G. (1996). User's Guide. *GrazeOn* - Pasture budgeting for better grazing management - mitchell grasslands. QDPI. Brisbane.

Cobon, D.H. (1996). *GrazeOn* - Pasture budgeting for better grazing management in the mitchell grasslands. DPI Note. QDPI. Brisbane. Agdex 133/940.

Cobon, D.H. (1996). *Adaptive management for sustainability in mitchell grass rangelands* (935472). Final project report to National Landcare Program. QDPI, Longreach.

Cobon, D.H., Pinington, G., and Scott, Q.B. (1997). *GrazeOn* - A pasture budgeting strategy for native grasslands. Proc.18th Inter. Grlds. Cong., Canada. 29, 141-2.

Stafford Smith, D.M *et al.* (1998). 'DroughtPlan—building on grazier participation to manage for climate variability' by Stafford Smith, D.M., Clewett, J.F., Moore, A.D., McKeon, G.M. and Clark, R., Occasional Paper CVO1/97. Land and Water Resources Research and Development Corporation, Canberra pp. 148.

Cobon, D.H. and Clewett, J.F. (1999). *DroughtPlan CD*. A compilation of software, workshops, case studies, reports and resource material to help manage climate variability in northern Australia. QZ90002, QDPI, Brisbane.

Links to other models – not linked with other models, but included with other models on the DroughtPlan CD.

Objective assessment – the model calculated short-term stocking rates equivalent to a 'safe' level of utilisation (<30% on mitchell grasslands. The inclusion of a non-utilised 440 kg/ha pasture defoliation threshold and the equivalent of the wet season pasture growth not fully utilised in 95% of years act as in-built safety mechanisms. These provide more certainty of the model being sustainable in terms of pasture and soil stability.

The main limitations of the method used to develop the model are (1) the low number and high variability of data used to estimate detached pasture, (2) not taking account of variability in resource use by grazing animals, (3) lack of suitable data describing relationships between *Astrebla* frequency, stocking rates and animal production and (3) the use of RUE's to estimate pasture growth.

B. DETAILED MODEL DESCRIPTION

Model features – Visual basic, empirical

Model processes – plant detachment, animal intake

Minimum data sets required – Nil

Parameter sets – parameters that are hard-wired in the model: TSDM, pasture condition, kangaroo numbers

Development/Validation data – grazing trials at Toorak Research Station, Julia Creek and Rosebank Research Station, Longreach

Sensitivity analyses – a sensitivity analysis was done to test how errors in model parameter estimation influenced the stocking rate calculations for a paddock. Each parameter in the model was varied by ±10% and the resulting variation in stocking rate was expressed as a percentage. Stocking rate was most sensitive to biomass, pasture condition index, biomass detached where a change of more than 10% in stocking occurred with a 10% variation in each of these parameters. For the other parameters a ±10% change resulted in a variation of less than 10% in stocking rate.

Model output – stocking rate (hd/ha)

Application – January to April in most years is the time for many pastoralists in the Qld Mitchell grasslands to decide how many animals the property will run until the end of the dry season (summer storms usually start in December). Others may have a number of decision points through the dry season and on some occasions they may be forced to revise previous decisions because of unexpected events that reduce pasture supply such as spoiling winter rain, plagues of locusts or upward shifts in the kangaroo population. All these circumstances provide an opportunity to use pasture budgeting as a practical and objective management tool to aid decision making in this region.

9. Kangaroo population model - Qld

- spatial and temporal dynamics of kangaroo populations in the sheep rangelands of eastern Australia.

A. OVERVIEW

Purpose/Objective – several models are being developed to predict kangaroo density at property and bioregional scale. This should allow kangaroo managers to optimise kangaroo harvest quotas and potentially land mangers to adjust sheep stocking rates.

Keywords – kangaroo, rainfall, NDVI, habitat selection, harvesting, environmental stochasticity, population dynamics, spatial correlation

Key contact/s –

Tony Pople
The Ecology Centre & Department of Zoology and Entomology
The University of Queensland Qld 4072, Australia
E-Mail: *TPople@zen.uq.edu.au*
Tel: (07) 3365 4831
Fax: (07) 3365 1655

Model status – under development. Supported by an ARC linkage (SPIRT) grant between UQ, State government conservation agencies, Federal DEH and the kangaroo industry.

Ownership/Availability – as the models are empirically based, there is a considerable amount of data for which background IP resides with State and Federal agencies and UQ. Models will be published and should be freely available.

History of development – long history of assessment of the environmental determinants of kangaroo density and relating kangaroo rate of increase to rainfall or pasture biomass. Current project is an extension of this work, using considerably more data (>20 years) and using new spatial analytical tools.

Documentation –

Jonzen N, Pople AR, Grigg GC, Possingham HP (In Press) Of sheep and rain. Regional dynamics and spatial correlation in the red kangaroo. *Journal of Applied Ecology*.

Pople A (2004) Population monitoring for kangaroo management. *Australian Mammalogy* **26**, 37-44.

Pople A (2003) 'Harvest management of kangaroos during drought.' Unpublished report to New South Wales National Parks and Wildlife Service, Dubbo, NSW.

Pople AR, Cairns SC, Menke N (2003) 'Monitoring Kangaroo Populations in Southeastern New South Wales.' Unpublished report to New South Wales National Parks and Wildlife Service, Dubbo, NSW.

Several other publications are currently being prepared.

Links to other models – potential links to GRASP.

Objective assessment – NDVI and rainfall may be poor surrogates of kangaroo food supply. Age and sex structure are currently ignored in models, but are being developed. Nevertheless, accuracy of modelled predictions may be adequate for management needs and inaccuracy can be offset by conservative management. Further development of models will be required beyond the life of the present ARC-funded project.

B. DETAILED MODEL DESCRIPTION

Model features – a range of empirically-based models are being developed:

- modelled dynamics of red kangaroos in SA, NSW and Qld at a regional scale. This work has explored the influence of harvesting, rainfall, intra-specific competition, sheep density and spatial correlation. Also examined at a finer scale.
- numerical response models relating kangaroo (four species) rate of increase to rainfall, NDVI and harvesting in regions of three states. This is again at a regional scale.
- environmental determinants of kangaroo distribution in SA, Qld and NSW. We hope to use habitat models to derive small-scale abundance estimates (by integrating under a fitted spatial density surface) and to determine unbiased broad-scale estimates from non-random surveys.
- determinants of kangaroo harvest sex ratio, skin size, carcase weight and CPUE. This should assess the value of these harvest statistics to indirectly monitor population size and harvest rate.

The actual models will range from simple 3-5 parameter equations to distribution maps generated interactively in a GIS.

Model processes –

- rate of increase of kangaroos as a function of some surrogate of food supply (e.g. rainfall, NDVI, modelled pasture biomass).
- density of kangaroos as a function of the environment (climate, soils, vegetation, NDVI, rainfall)

Minimum data sets required – rainfall, possibly NDVI, harvest off-take.

Parameter sets – parameters are likely to be hard-wired.

Development/Validation data –

- aerial survey data of kangaroo density (1975-2003).
- harvest statistics
- rainfall
- NDVI
- range of environmental datasets

Sensitivity analyses – confidence intervals for predictions, cross validation, assessment of alternative models.

Model output – kangaroo density or rate of increase and possibly harvest rate.

Application –

Harvest management of kangaroos relies on regular direct monitoring that is expensive. Modelled predictions of kangaroo numbers may allow a reduced frequency of monitoring, at least in some years, and possible revision of quotas between annual aerial surveys. Harvest quotas are currently set on previous years' population estimates, so forward predictions should allow more accurate quota setting. Indirect monitoring of populations may also be possible using rainfall or NDVI based models or using harvest statistics that are collected continuously by state agencies. Habitat models should allow small-scale predictions of kangaroo density, providing an objective means for setting quotas and allocating harvest tags at this scale.

How these models may be incorporated into harvest management is being examined using a risk assessment of harvest strategies. This work explores the tradeoffs (in terms of risk of quasi-extinction, cost of management and harvest off-take and CV) involved in varying harvest rate, survey frequency and harvest thresholds. The influences of environment and model structure have also been examined.

10. Kangaroo population model - NSW

- a model of kangaroo population dynamics in western NSW under differing harvest strategies

A. OVERVIEW

Purpose/Objective – the model was developed to examine the impact of different harvest strategies, with respect to age and sex, on kangaroo population dynamics to ascertain the strategy best suited to the objectives of various stakeholder groups (government wildlife management agencies, conservationists, pastoralists, and the kangaroo industry).

Keywords – sustainable use, commercial wildlife harvesting, kangaroos, wildlife management, rangelands, age, sex, multi-criteria decision analysis

Key contact/s –

S.R. McLeod
NSW Agriculture
Vertebrate Pest Research Unit
Forest Road, Orange, NSW 2800
Email: *steven.mcleod@agric.nsw.gov.au*
Tel: (02) 6391 3810

Model status – the model is still under development.

Ownership/Availability – the model is owned by NSW Agriculture. Availability is by direct contact with S.McLeod.

History of development – the model has only recently been developed and is not yet widely applied

Documentation – a general description of the model is given in McLeod *et al*. (2004), while detailed documentation of the model is still in progress.

McLeod SR, Hacker RB and Druhan JP, 2004. Managing the commercial harvest of kangaroos in the Murray-Darling Basin. *Australian Mammalogy* **26**: 9-22.

Links to other models – None

Objective assessment –

The model has been parameterised on red kangaroo living in chenopod shrublands in the far west of NSW. Suitable parameterisation would be required for other species in other vegetative regions. The model connects kangaroo fecundity and survival to pasture biomass, which in turn, is affected by rainfall and kangaroo population density. The strength of the model is the ability to alter the proportion of animals harvested, the ratio of male:female animals harvested, and to set the age of animals harvested (or minimum carcase size). The weaknesses of the model include: its highly empirical nature using a set of complex partial derivatives (that may make it more difficult for others to parameterise the model to their situation); it uses only a quarterly time-step; and has no link to habitat availability i.e. distance to water, available refuge etc. The models only link to the environment is through pasture biomass. The model has a limited stochastic element but this is merely selecting rainfall as a random draw from a normal distribution.

B. DETAILED MODEL DESCRIPTION

Model features – the model uses a continuous-time approach and can be run over 100 years, but runs on a quarterly time-step. It has no spatial component, and is entirely empirical.

Model processes – the main processes within the model are :

- Population structure based on age specific birth and death rates
- Male and female dynamics modelled separately
- Harvest off-take modelled as a form of mortality that is age and sex specific
- Multi-criteria decision analysis (MCDA) is used on identified attributes ranked to reflect their relative importance, summed and checked for sensitivity in weighting

Minimum data sets required – quarterly rainfall

Parameter sets – the main parameters required are:

- Pasture growth in relation rainfall and kangaroo density
- Intake in relation to age and sex of animal
- Age specific survivorship of kangaroos
- Age of female sexual maturity and senescence
- Fecundity and survival rates with respect to pasture growth

Development/Validation data – the model results are presently being tested against data collected for other species.

Sensitivity analyses –this is done as part of the MCDA.

Model output – summed MCDA values, kangaroo and pasture yields.

Application –

The derived model can be used to evaluate long-term (100 year) impacts of a range of harvest rate and sex combinations on kangaroo populations and pasture on which they feed. Analysis of the model output will help identify harvest rate and bias combinations that the different stakeholders will need to accomplish to achieve certain management objectives. While the objectives of the different stakeholders (government wildlife management agencies, conservationists, pastoralists, and the kangaroo industry) are sometimes mutually exclusive, this model will help identify harvest options with greatest scope for reconciling the differences.

11. RAB_POP

- a rabbit population model for Queensland

A. OVERVIEW

Purpose/Objective – the model was designed to enable the population dynamics of rabbits to be understood. The introduction of rabbit calicivirus led to a large drop in rabbit populations, especially in semi-arid parts of the state. However, in sub-coastal parts, rabbit populations continued to thrive, albeit at a lower population density. The model has allowed the climatic effect on populations to be accounted for.

Keywords – RCV; RCD; RHDV; RHD; rabbits; grazing; myxomatosis; ripping; antibodies (Note: RCV – rabbit calicivirus and is now more properly referred to as RHDV rabbit haemorrhagic disease virus; RCD rabbit calicivirus disease, now more properly referred to as RHD rabbit haemorrhagic disease)

Key contact –

Joe Scanlan
Robert Wicks Pest Animal Research Centre
Natural Resources, Mines and Energy
Toowoomba Qld 4350
Email: *Joe.Scanlan@nrm.qld.gov.au*
Tel: (07) 4688 1243

Model status – the model is under development, although it has not substantially changed for a few years. It has not been tested against populations in other states.

Ownership/Availability – the model was developed on departmental funds only, so IP would reside in NRM&E. It would be freely available to fellow researchers interested in evaluating/developing the model.

History of development – the model commenced in 1998 when Dr Bill Grant from Texas A&M University visited RWPARC for a month. It has since been developed, and has been tested against any historical population data (spotlight counts) that we can readily access. Dr David Berman and Russell Palmer provided rabbit biology information for inclusion in the model.

Documentation – the model has not yet been published but has been used in a minor way for a publication (in press) in Wildlife Research.

Links to other models – the output from GRASP (monthly growth) is an input into RAB_POP. No comparisons have been made with other models.

Objective assessment –

Strengths:

- incorporates major control options/diseases
- can be readily modified (developed within the STELLA environment)
- has been tested against data for multiple years at 14 sites, both pre and post RHDV
- can be used to examine climate change impacts

Weaknesses & limitations:

- only tested within Queensland
- does not have any spatial aspects of disease spread
- diseases become fully active and effective within one month, whereas in reality they follow a pattern of development

- potential pasture production has to be input from another model and so the feedback of numbers on growth is not dynamic. However, growth is used as an assessment of quality and the quantity is not crucial to the model as it currently stands.

B. DETAILED MODEL DESCRIPTION

Model features –

- Developed in STELLA environment
- Point model
- More mechanistic than empirical
- Monthly time step

Model processes –models fertility, natality and mortality of rabbits, with temperature, pasture quality, grazing competition from livestock and diseases/ripping as influences on these processes.

Minimum data sets required – monthly mean temp; monthly pasture growth and livestock stocking rate are mandatory.

Parameter sets – litter size; mortality rates due to diseases; thresholds for disease occurrence are key parameters that would be required if extended to other areas.

Development/Validation data – spotlight counts of rabbits around Roma Goondiwindi in the 1970s (8 sites). Six sites used for RCV Monitoring program (1996-2000)

Sensitivity analyses – nothing formal.

Model output – any state variable, auxiliary variable, transfer or parameter is able to be output at every time-step.

Application – see Purpose/Objective above

12. Range-ASSESS

- scenario tool for carbon change in grazed rangelands

A. OVERVIEW

Purpose/Objective – Range-ASSESS was constructed to examine the potential effects of changes in management of livestock and other grazing animals on carbon stocks in Australian rangelands. The model is designed to combine knowledge and with spatial data to capture the major dynamic components of the system – fire, grazing, climate – and explore the overall problem space. It provides indications of direction and magnitude of changes but is not intended for quantitative use.

Keywords – grazing, climate, fire, soil and biomass carbon, state and transition models, thresholds, logical rules, knowledge-based approach, heuristic modelling

Key contact/s –

Michael Hill
CRC for Greenhouse Accounting and Bureau of Rural Sciences
PO Box 858
Canberra, ACT, 2601
Email: *michael.hill@brs.gov.au*
Tel: (02) 6272 5317

Stephen Roxburgh
CRC for Greenhouse Accounting and Research School of Biological Sciences
Australian National University
Canberra, ACT, 0200
Email: *stephen.roxburgh@anu.edu.au*

Model status – Range-ASSESS is operational and will be completed by June 30, 2004. Range-ASSESS is a flexible, user driven, knowledge-based system and the concept of validation has no meaning for this package. It has been developed through funding from the CRC for Greenhouse Accounting.

Ownership/Availability – IP for Range-ASSESS resides with the CRC for Greenhouse Accounting and its constituent agencies. It is not yet available but we anticipate that a version will be made available by some means, possible Internet, after June 30.

History of development – Range-ASSESS was initially developed in late 2000 by construction of a prototype and then incorporation of rangeland knowledge through a workshop with rangeland experts in September 2000. This work was carried out by Robert Braaten and Michael Hill. It was initially written in ARC AML. In 2003, the package was ported to the BORLAND DELPHI programming environment making it fully standalone. This work and all subsequent work has been carried out by Stephen Roxburgh and Michael Hill. Another workshop with rangeland experts was held in June 2003 to examine progress and prioritise enhancements. Greg McKeon and John Carter have played key roles in development and provide the basis of rangeland expertise underpinning the work. Subsequently the number of rangeland zones was expanded to 12, factorial and Monte Carlo analysis capability was included, climate impact was made spatially explicit through incorporation of 6 year type growth deviation layers, and 2 additional safe carrying capacity layers were added. Range-ASSESS has been used in a recent consultancy and an analysis of grazing x climate interaction for soil carbon outcomes in 5 year reporting periods is currently being completed.

Documentation –

Hill, M. J., Braaten, R., McKeon, G., Barrett, D., Dyer, R. and seven others (2002). Range-ASSESS: A spatial framework for analysis of potential for carbon sequestration in rangelands. *Technical Publication No. 1*, CRC for Greenhouse Accounting, ANU, Canberra, 43 pp.

Hill, M. J., Braaten, R. and McKeon, G. (2003) A spatial tool for evaluating the effect of grazing land management on carbon sequestration in Australian rangelands *Environmental Modelling and Software*, 18, 627-644.

Hill, M. J., McKeon, G. M., Roxburgh, S. J. and Barrett, D. J. (2004). Scenario analysis of grazing land management impacts on soil carbon storage in Australian rangelands. *Environmental Modelling and Software* (in preparation)

Links to other models – Range-ASSESS depends upon pre-settlement steady state soil and biomass carbon surfaces for Australia derived from the VAST 1.1 model (Barrett, 2002).

Objective assessment – Range-ASSESS is a mixed model combining spatial data and expert knowledge at a range of scales without any time step. The key component is a set of state and transition models for each rangeland zone derived from expert knowledge and providing relative carbon indices for each carbon state (relative to an original state 1.0). Spatially explicit driver layers for fire frequency (only operates for northern tallgrass zone), stocking rate and safe carrying capacity, and growth deviation for climate year type (6 types – 3 dry and 3 wet), are transformed into fire, grazing and drought indices (1 – 5) and control transitions between carbon states using a set of logical transition rules. Changes are assumed to occur over defined periods and are manifested by multiplication of carbon layers by indices. Time effects are only accounted for by a ratio between the 5 year reporting period and the deemed period for full expression of change.

Range-ASSESS is designed to explore the problem space and is not a mechanistic model nor is it intended for accounting use in anyway. It contains some gross spatial approximations and alignment of zones and VAST carbon layers is inexact and has particular inaccuracies for biomass for some zones where open scrub exists but state and transition models do not account for a woody component. The model outcomes depend entirely upon the assumptions used, state and transition model constructs, relative carbon indices and the values of thresholds and types of input layers used all of which are adjustable by the user.

B. DETAILED MODEL DESCRIPTION

Range-ASSESS is completely self-contained and does not require any data input. Users can use alternative input layers provided and change most thresholds and parameters used since it is a knowledge-based approach.

Descriptions are available in the publications listed above. The adjustments to the latest version will be reported in a paper to be submitted shortly.

13. TREEGRASS - 3D
- savanna production and water balance model

A. OVERVIEW

Purpose/Objective – TREEGRASS was specifically developed to address the issue of tree individual spatial arrangement on tree and grass productivity and water balance, i.e. to answer questions like; is productivity different if trees are regularly scattered or if they are clumped? And if some effects were shown, the model could be used as a calibration tool to account for fine scale vegetation structure in coarse resolution models.

Keywords – spatial patterns, radiation transfer, individual-based model, water balance, tree/grass interactions, spatially explicit model

Key contact/s –

Guillaume Simioni
CSIRO Forestry and Forest Products, PO Box E4008, Kingston ACT 2604
Email: *Guillaume.Simioni@csiro.au*
Tel. (02) 6281 8406
Fax. (02) 6281 8312

Jacques Gignoux, CNRS, Paris, France (gignoux@wotan.ens.fr)
Xavier Le Roux, INRA, Lyon, France (leroux@biomserv.univ-lyon1.fr)
Nicolas Boulain, University Paris 6, Paris, France (boulain@wotan.ens.fr)

Other people associated :
Hervé Sinoquet, INRA, Clermont-Ferrand, France
Gaëlle Lahoreau, University Paris 6, France

Model status – two versions were developed (and various sub-versions). Both are fully operational and have been tested on a humid West African savanna (Lamto, Ivory Coast). The first version was run on a mulga site in Australia, and the second version was also parameterised for a sahelian savanna in Niger, West Africa.

Ownership/Availability – the model can be made available after contacting the developers.

History of development – the first version was developed in 1998 by Simioni, Le Roux, Gignoux, and Sinoquet, as part of my master degree. The second version was terminated in 2001, by Simioni, Gignoux, and Le Roux, as part of my PhD degree. Since then, other students have used and adapted the model for various purposes (calibrating large scale models, study seedling light environments…).

Documentation – there is no user's guide document specifically written. To date two publications have been released:

Simioni G, Le Roux X, Gignoux J, and Sinoquet H. 2000. TREEGRASS: a 3D, process-based model for simulating the functioning of tree-grass ecosystems. *Ecological Modelling* 131:47-63.

Simioni G, Gignoux J, and Le Roux X. 2003. How does the spatial structure of the tree layer influence water balance and primary production in savannas? Results of a 3D modelling approach. *Ecology* 84:1879-1894.

Links to other models – the first version was developed within the ecosystem modelling shell MUSE (Gignoux *et al*. 1997). TREEGRASS was part of an international model inter-comparison study under the SCOPE program for tree/grass interactions, in 1998-1999. Other models were GRASP, CENTURY, and SAVANNA.

Objective assessment –

Strengths

With its fine scale fully spatial representation, TREEGRASS is particularly suitable to investigate the effect of vegetation fine scale structure on production and water balance.

Limitations

TREEGRASS is limited to time scales of one to a few years. The model focuses on plant-plant competition for light and water, but nutrients are not explicitly represented.

B. DETAILED MODEL DESCRIPTION

Model features – the first version was implemented in the MUSE modelling software in Borland Pascal 7. It was translated in C++. The second version was developed in C++. The C++ versions have no interface but can be run under Windows- or Unix/Linux-based computers. There are also some versions in Delphi/Kylix (contact J Gignoux or N Boulain for more detail).

Model processes –

Radiation budget:

- Comprehensive 3D radiation budget: account for diffuse and direct radiation, PAR and infra-red, and reflection and transmission by foliage and soil surface.
- 3D energy budget, which determines plant transpiration and soil evaporation.

At the plant individual level:

- Direct conversion of absorbed light into dry matter (first version), or full C3 and C4 photosynthesis representation (second version).
- Stomatal conductance (used for transpiration and photosynthesis).
- Growth allocation between shoot and roots (grass) or between leaves, stem and roots (trees).
- Water extraction from the soil.
- Water stress feedbacks on production, transpiration, and water extraction pattern.

Soil water balance: several soil layers possible, runoff, rainfall input, water flux down the profile (bucket model), and deep drainage.

Basic fire effect.

Minimum data sets required –

- daily rainfall and radiation
- infra-day air temperature and humidity

Parameter sets –

- Site latitude.
- Species composition.
- Tree spatial positions.
- Leaf angle distribution and leaf reflectance/transmittance properties (including for dead grass standing leaves).
- Fixed specific leaf area (first version).
- Seasonal course of leaf nitrogen and specific leaf area, with effects of leaf light microenvironment (second version).
- Stomatal conductance response to PAR, VPD, and water stress (all versions), and link with leaf nitrogen (second version).
- Light conversion efficiency into dry matter (first version), or parameters needed to run C3 Farquhar and C4 Collatz photosynthesis models (second version).

- Growth shoot-root allocation, and effect of water stress.
- Tree maximum individual leaf area index.
- Tree allometry (relationships between height and foliage depth, canopy extent, and root extent).
- Leaf senescence.
- Standing dead leaves disappearance rate (grasses).
- Species water extraction patterns, and effects of water stress.
- Field capacities and wilting points for the relevant soil layers.

Many parameters listed above are species-specific, not necessarily site specific.

Development/Validation data –

Extensive measurements were made in the Lamto savannas for parameterisation, including:

- Comparisons of species shoot water potential and soil water content (to asses how water stress occurs).
- Comparison of isotopic composition of soil water and plant stem water (where plants extract water).
- Leaf gas exchange (photosynthesis and stomatal conductance).
- Survey of tree leaf area and leaf properties during a whole vegetation cycle (maximum leaf area, specific leaf area and leaf nitrogen).
- Sampling of tree leaves at different positions in canopy, with hemispherical photographs taken at leaf position (relationships between leaf properties and light environment).
- Survey of grass leaf cohorts during a vegetation cycle.

The parameterisation of carbon loss through respiration and root exudation (second version) was made from data in the literature.

Other data were collected at Lamto for model testing:

- Temporal and spatial variations in grass standing biomass and necromass, and of soil water content (allowed a spatial test of TREEGRASS).
- PAR interception by the tree layer.
- Field estimation of productivity in stands of various tree cover.

Sensitivity analyses – no rigorous sensitivity analysis to the entire set of parameter has been conducted, mainly because of the large number of parameters. Nonetheless, having used the model extensively, I have a personal idea about how it responds to various changes in parameters. The radiation transfer model proved to be very robust, and leaf optical properties do not vary greatly between species. Changes in leaf angle distribution are important only if they affect significantly light absorption. Many eucalypt species have vertically hanging leaves, which intercept much less light than, say, an apple tree, which has many leaves positioned more or less horizontally. Parameters linked to production and stomatal conductance are paramount. Plant water extraction pattern is important, as in some systems trees and grasses share the same water resource (as is roughly the case in Lamto), while in other systems trees uptake water in deeper layers than grasses.

Model output – the model tracks light absorption, primary production, transpiration, leaf biomass and leaf area at the plant level, and soil water content and soil evaporation at the soil cell level.

Application –

The model was applied to:

- assess the effect of the spatial arrangement of tree individuals on net primary production and transpiration (published, see above).
- Study the tree cover effect on soil water content and grass growth under various rainfall regimes (in prep).
- Study the interaction between tree layer spatial structure and the type of tree-grass association (C3 or C4 grasses) on primary production, water balance, and ecosystem resource use efficiencies (in prep).
- Calibrate a simple method for accounting for vegetation structure at large spatial scales (Boulain at al., submitted).
- Study tree seedling survival linked to their light environment (Lahoreau, in prep).

14. WALTER

- long-term change in arid zone shrub populations

A. OVERVIEW

Purpose/Objective – the model was originally built to investigate the varying impacts of continuous and episodic change on arid zone shrub populations (see Watson *et al.* 1997). Subsequently, it was expanded to provide a means of modelling outputs from Western Australian Rangeland Monitoring System (WARMS) sites (see Watson 1999). More recently it was further developed to investigate the pattern and timing of resource degradation (i.e. change in shrub populations) over decadal timescales (see Watson *et al.* in proof/press)

Keywords – demography, arid zone shrubs, grazing impact, seasonal impact, transition matrix, projection matrix, stage classified, time varying.

Key contact –

Ian Watson,
Department of Agriculture Western Australia and the Centre for Management of Arid Environments.
PO Box 483, Northam, WA, 6401.
Email: *iwatson@agric.wa.gov.au*
Tel: (08) 9690 2000; Fax: (08) 9622 1902; Mobile: 0427 477 734

Model status – the model is still under development. Development is sporadic and on a needs basis. It is supported by the Department of Agriculture Western Australia, but not in any formal way.

Ownership/Availability – the model is freely available as are the data sets used to parameterise the model. No consideration has been given to IP, but it is unlikely to ever be an issue.

History of development – model development began during Ian Watson's PhD studies (1994-1996). It was expanded for the purposes of investigating changes within WARMS (1999) and then further expanded (1999-2003) within Qld DNRM&E's "Learning from History" projects (managed by Greg McKeon). Ian Watson is the only developer.

Documentation – there are no published references describing the model, nor is detailed documentation available. However, some of the model concepts are described in Watson (1998).

Watson, I.W. (1998). Monitoring Western Australian shrublands; what are the expectations of change? *Range Management Newsletter*, **98/2**, 1-5.

Watson, I.W. (1999). A model of expected change on Western Australian range monitoring sites. *Proceedings, VI International Rangeland Congress.* (Eds; D. Eldridge and D. Freudenberger). Townsville, July 1999, 844-845.

Watson, I.W., Westoby, M. and Holm, A.McR. (1997). Continuous and episodic components of demographic change in arid zone shrubs: models of two *Eremophila* species from Western Australia compared with published data on other species. *Journal of Ecology,* **85,** 833-846.

Watson, I.W., McKeon, G.M. and Wilcox, D.G. (in press/proof). Modelling climate and management effects on shrub populations in the Gascoyne area of Western Australia and the North East District of South Australia. In: *Learning from history. Can seasonal climate forecasting prevent land and pasture degradation of Australia's grazing lands?* (Eds: G.M. McKeon, W. Hall, B.H. Henry, G. Stone and

I.W. Watson). Queensland Department of Natural Resources and Mines, Brisbane, Australia.

Links to other models – there are no instances of WALTER being linked to other models.

Objective assessment – the model allows long term change in shrub populations to be investigated. The use of transition matrices allows easily collected data to be used to parameterise the model. The time-varying approach allows different year-types (e.g. wet, ordinary and dry) to be modelled, as well as two different stocking rates. Time step is nominally annual but is independent of the model formulation. The model type (i.e. time varying transition matrix) has a substantial literature behind it (e.g. Caswell H. 2001. Matrix population models: construction analysis and interpretation. Sinauer and Associates).

Weaknesses of the model include the fact that it is used for modelling over long periods (c. 100 yrs) but data with which to parameterise the model are available for much shorter periods (e.g. <10 yrs). There are no feedback loops to allow for density dependence, the inclusion of recruitment is weak and it is a single species model in an environment where community dynamics are important. The definition of year-type is somewhat arbitrary, although this occurs outside the model. The definition of when an age classified individual (i.e. a known recruit) enters the stage classified population (i.e. where size rather than age determines matrix cell) is arbitrary and would be improved by better knowledge of plant physiology and phenology by species. Stocking rate impacts are derived from empirical observation rather than a mechanistic understanding of the impact of grazing on plant survivorship and growth.

Technically, the improvement of the model is not difficult, although beyond the current resources of Ian Watson. However, a similar (and hopefully more sophisticated) model will be developed within a Desert Knowledge CRC project, managed by Fleur Tiver of the University of South Australia (Project Title = A mathematical-ecological model with flexible computer implementation for sustainable management of shrublands)

DETAILED MODEL DESCRIPTION

Model features – the model is written in dBase IV code and will run in Visual dBase. The time step is nominally annual, although time step is independent of the model formulation. It allows two different stocking rates and three year types. Stocking rates can be altered dynamically in response to changes (i.e. “rules”) within the shrub populations. The model is empirical.

Model processes – shrub demography, i.e. recruitment, mortality and change in size class.

Minimum data sets required – year type (3) is decided outside the model and used as an input. It is an arbitrary assessment based on judgement, local knowledge, rainfall or some other means of differentiating the impact of wet, dry and ordinary years. Demography data are at the individual plant level. That is, the fate of plants is tracked over time in terms of survivorship and size change. Transition probabilities (which drive the model) are derived from the fate of each individual. That is, of Y individuals at $time_X$, what proportion die; and of the survivors, what proportion change size class by $time_{X+1}$? The recruitment rate is determined as a proportion of mature individuals in selected stage classes (i.e. recruitment information is held within the transition matrix).

Parameter sets – year type and length of model run are user determined. Transition probabilities of the plant population (recruitment, survivorship and size change) are derived from the demographic data set. The model is hard-wired to 4 stages (1 recruit stage and 3 mature stages). Grazing management rules (e.g. stocking rate is lightened when the proportion of small individuals reaches “X”) is hard-wired although X” is user determined.

Development/Validation data – shrub demography data collected as part of the Boolathana grazing study (near Carnarvon Western Australia – details in Watson *et al.* 1997). No real validation of the model. Model has only been run operationally with parameter estimates from two species from Boolathana.

Sensitivity analyses – Nil.

Model output – shrub demography data over time – summarised as shrub density. However, the demography data can be broken into recruitment, survivorship and proportion of the population in various stage classes.

Application – the model has been applied to investigate shrub demography changes at semi-decadal timescales on rangeland monitoring sites (Watson 1999), semi-century timescales to investigate the relative impacts of continuous and episodic changes (Watson *et al*. 1997) and century timescales to explore long-term degradation patterns since pastoralism began (Watson *et al*. in proof/press).

Category 3 - These are models that are directly relevant to the rangelands but, for various reasons, are no longer in use or under development.

1. AridGro

- a simple model of herbage production for arid landscapes

A. OVERVIEW

Purpose/Objective – AridGro was developed to predict herbage production at the landscape scale as affected by land degradation and rainfall variability in central Australia.

Keywords – arid zone, herbage, production, rainfall, land degradation

Key contact/s –
Geoff Pickup
[formerly] CSIRO Wildlife & Ecology, Alice Springs, NT

Current contact:
John Ludwig
CSIRO Sustainable Ecosystems
Atherton, QLD.

Model status – the AridGro model was developed by Trevor Hobbs for Geoff Pickup at CSIRO, Alice Springs. It is operational, but is not currently being used or developed further.

Ownership/Availability – the IP for AridGro is held by CSIRO.

History of development – AridGro was developed by Trevor Hobbs for Geoff Pickup at CSIRO, Alice Springs, in the early 1990's.

Documentation – the AridGro model is described in two scientific journal papers by Geoff Pickup published in 1995 and 1996.

Pickup, G. (1995) A simple model for predicting herbage production from rainfall in rangelands and its calibration using remotely sensed data. *Journal of Arid Environments* 30: 227-245.

Pickup, G. (1996) Estimating the effects of land degradation and rainfall variation on productivity in rangelands: an approach using remote sensing and models of grazing and herbage dynamics. *Journal of Applied Ecology* 33: 819-832.

Links to other models – the AridGro model was specifically developed to link to remotely sensed data for the aridzone.

Objective assessment – AridGro was specifically developed to estimate the effects of different land degradation patterns and also variations in rainfall patterns over the arid landscapes of central Australia. This model has been reasonably well verified using remotely sensed data (Pickup 1995, 1996)

2. EDYS

– ECOLOGICAL DYNAMICS SIMULATION: a mechanistic model of vegetation dynamics and soils in response to management disturbances such as grazing, fire, military training, or contaminants.

A. OVERVIEW

Purpose/Objective – the Ecological DYnamics Simulation (EDYS) model is a PC-based, mechanistic simulation model developed to simulate changes in all components of ecological systems resulting from natural and anthropogenic ecological stressors. It can be applied to a wide variety of ecosystems and numerous disturbance and management scenarios such as grazing, fire and military training activities. It was developed in the USA and has been applied in Australia at the Townsville Field Training Area in north Queensland.

Keywords – vegetation dynamics, soils, grazing, fire, military training

Key contact/s – Applied in Australia by:

Andrew Ash
CSIRO Sustainable Ecosystems
306 Carmody Rd
St. Lucia
Qld 4061
Email: *Andrew.Ash@csiro.au*
Tel: (07) 32142346

USA Contact:
Dr Terry McLendon
MWH
380 Interlocken Crescent
Suite 200
Broomfield, CO
USA 80021
Tel: +01 (303) 533 1900

Model status – EDYS is currently in use and under active development and application. Its main application has been in US military training areas.

Ownership/Availability – the IP for EDYS is held by MWH/Dr Terry McLendon.

History of development – EDYS commenced its development in the 1980s with Drs Terry McLendon and Dr Mike Childress. Development continued through the 1990s with Sheperd Miller Inc until the late 1990s by which time Version 4 was being applied on a number of military training areas in the USA.

Documentation –

Childress, WM; Coldren, CL; McLendon, T . (2002) Applying a complex, general ecosystem model (EDYS) in large-scale land management. *Ecological Modelling* **153**: 97-108

Links to other models – the AridGro model was specifically developed to link to remotely sensed data for the arid zone.

Objective assessment –

EDYS is a mechanistic model that aims to simulate ecosystem dynamics by incorporating all important processes which affect ecosystem function. To achieve these aims, it necessarily becomes a fairly complex model with a large number of parameters. Many of these parameter values do not exist in datasets collected in northern Australia. In parameterising EDYS for assessing the impacts of military training activities in tropical savannas there was a heavy reliance on literature values and expert judgement to get the model up and running. The time required to assemble these parameters and understand their context within the model so sensible adjustments can be made, should not be underestimated.

EDYS was capable of simulating basic ecosystem dynamics in these savanna environments. When run for 50 years using the historical climate record for Charters Towers the model realistically simulated the inter-annual variability in the tree, shrub and herbaceous layers. The model was able to simulate increases in exotic plants and increases in native shrubs in the absence of fire. The levels of primary production predicted by EDYS were consistent with what is observed in the field and showed reasonable agreement with the forage production model GRASP, which has been well validated for these savanna environments. The model evaluation process highlighted the need for a better biological understanding of below-ground processes and the processes of senescence, detachment and decay in above-ground biomass. When disturbances such as fire and training were implemented in the model the responses in plant community dynamics were generally as expected.

3. FEEDMAN 3.0

- a feed-to-dollars beef and deer management package

A. OVERVIEW

Purpose/Objective - FEEDMAN 3.0 is a computer program that helps beef and deer producers compare feeding options for animal production. It has been designed for farms in central and south-east Queensland. After describing the paddocks, soil types and forages on a farm, forage growth and sustainable stocking rates are calculated from monthly rainfall, which can be entered directly or selected from the historical records supplied. Mobs of cattle or deer can be allocated to each paddock and liveweight and market options, including velvet antler for deer, and sales for each mob are estimated, together with mob and farm economics. Results appear as table or graphs that can be printed. Key input data can be changed to reflect local conditions. Thus FEEDMAN 3.0 allows a wide range of farm scenarios to be tested, including comparing beef and/or deer production, different forage and grazing sequences, and options for stocking rates, supplementary feeding and markets. Any farm management scenario can be stored for future use or modification.

Keywords - decision support systems, grazing systems, feed year planning, beef production, beef cattle, deer production, velvet production

Key contacts

Dr Ken Rickert
(formerly) School of Natural and Rural Systems Management
University of Queensland, Gatton Campus, Gatton, Qld 4343
Email: *janrickert@bigpond.com*
Tel: (07) 5460 1047

Mr Stephen Sinclair
Queensland Department of Primary Industries and Fisheries, Rockhampton
E-mail: *stephen.sinclair@dpi.qld.gov.au*
Tel: (07) 49360325

Model - FEEDMAN 3.0 is fully operational.

Ownership/Availability - FEEDMAN 3.0 can be purchased from the Queensland Department of Primary Industries and Fisheries. The University of Queensland holds copyright. Key data and a technical manual are supplied with the package. Users agree not to hold the authors and publisher liable for loss or damage that occurs from using the software, or for defects in the software.

History of development - FEEDMAN 2.0 was developed between 1993 and 1996 by Ken Rickert, Peter Thompson and Greg McKeon with support from Meat & Livestock Australia. The mathematical relationships were derived from results of past research and the simulation model GRASP, and validated against independent research results. After further evaluation by a panel of four potential users in a range of locations, FEEDMAN 2.0 was published by the Queensland Department of Primary Industries, but because it was not Y2K compliant it was withdrawn from sale. FEEDMAN 3.0 was subsequently developed by Stephen Sinclair and Ken Rickert with support from Rural Industries Research and Development Corporation. It also allows a wider range of tactical and strategic management options to be tested by expanding the range of livestock classes and forages in version 2.0 to include breeding cows, red deer, rusa deer and irrigated forages. Both versions are based on Microsoft Access®.

Documentation

Sinclair, S.E., Rickert, K.G. and Pritchard, J.R. (2000). *FEEDMAN - A feed-to-dollars beef and deer management package*. Version 3.0 QZ00004, Department of Primary Industries, Brisbane.

Rickert, K.G. and Sinclair, S.E. (2000). *FEEDMAN - A feed-to-dollars beef and deer management package*. Version 3.0 Technical Manual. 30pp. QZ00004, Department of Primary Industries, Brisbane.

Sinclair, S.E. and Rickert, K.G.(2000). An overview of the incorporation of management systems for red and rusa deer in Queensland within a decision support system. *Asian-Australasian Journal of Animal Sciences*, 13 Supplement C, pp 292-294.

Links to other models - See item 7: GRASP, FEEDMAN 2.0, FEEDMAN 3.0.

Objective assessment

Strengths of FEEDMAN 3.0 include:

- Users can test a wide range of management options for forages and livestock on beef cattle farms in southern and central Queensland.
- Complex farm scenarios can be described in terms of monthly rainfall and paddocks that may contain one or more soil types and/or forages, which can be grazed on a month by month basis by mobs of livestock specified by number, weight, breed and class.
- Default values for key biological and economic variables that are supplied with the package can be modified to reflect local conditions.
- Year-long farm scenarios can be stored, recalled and updated as circumstances such as rainfall and markets change.
- Year-long farm scenarios that are updated with actual data become a comprehensive historical record of paddock and livestock management and the economics of beef and/or deer enterprises.

Weaknesses of FEEDMAN 3.0 include:

- Users need to become familiar with the package and take the time to describe the farm paddocks, forages and livestock in local terms, and regularly update input costs and market prices.
- Although help notes and tutorials assist in this familiarization process, users need reasonable levels of commitment and computer skills to master and effectively use FEEDMAN.
- There has been no ‘champion’ to alleviate these problems by running training schools or otherwise promoting the package.

4. GRIM

– GRowth Index Model for calculating climatic indices affecting plant growth.

A. OVERVIEW

Purpose/Objective – GRIM was developed to assist in modelling of pasture growth. It brings together numerous relationships from the literature to allow indices of moisture availability, radiation, temperature and growth to be calculated for a range of soil types and climatic regions. The original model has been extended to generate counts of 'Green days'.

Keywords – Indices, moisture, temperature, radiation, growth, climate

Key contact –

Cam McDonald
CSIRO Sustainable Ecosystems
306 Carmody Road, St Lucia Q 4067
Email: *cam.mcdonald@csiro.au*
Tel: (07) 3214 2289

Model status – the model is fully operational and has been used extensively in the past both in Australia and overseas for calculating climatic indices. However, with the advent of more sophisticated models of pasture growth, no further development is likely. The functions taken from literature have been validated prior to their publication. The soil moisture component GRIM has been validated on some granite (sandy) and brigalow (heavy clay) soils.

Ownership/Availability – the model is owned by CSIRO but is freely available. However, it was written under DOS and will not run under Windows 2000, but will run under Windows 95 and 98. Examples of key climate data required are available.

History of development – development of GRIM began in the late 1980's as part of work on predicting pasture growth and animal liveweight gain. Initial attempts to relate liveweight gain to pasture biomass being unsuccessful, GRIM was developed to provide better indicators of periods of pasture growth and pasture quality. Initially the program was specific to granite soils in south-east Queensland, but others saw wider potential uses hence the model was expanded to include relationships for different temperature zones and soil types. In the late 1990's the model was expanded to include the calculation of 'green days', and graphical output to screen.

Documentation – Version 2.33 of GRIM was fully documented in a technical memorandum in 1994, however this manual does not include the section on 'green days'.

McDonald,C.K. (1994) Calculating climatic indices affecting plant growth. CSIRO Australia, Division of Tropical Crops & Pastures, Tropical Agronomy Technical Memorandum No. 83.

Links to other models – no direct links have been made however, output has been linked to oceanographic temperature models for climate forecasting in northern Australia, and to development of species population models.

Objective assessment – the model is very flexible and easy to use however, some knowledge is required of soil moisture processes for any particular soil type selected. GRIM runs on a daily time step and hence requires daily climate data of rainfall, evaporation, maximum and minimum temperatures, and for frost incidents, the grass minimum. If vapour pressure deficits are required then 0900 wet and dry bulb temperatures are required also. The model has several output options and which include daily output of indices and cumulative output over a user specified time period. All output is written to file in ASCII format. While running, the model displays continuous graphs of indices on screen which enables any anomalies to be more readily identified. GRIM is a useful tool for calculating climatic indices which can then be related to other measurements.

5. IMAGES

- An Integrated Model of an Arid Grazing System

A. OVERVIEW

Purpose/Objective – IMAGES is a vegetation model designed to investigate the probability of recruitment and mortality of selected species under different grazing management. The model was developed to evaluate management strategies and identify ecological processes and research priorities in Western Australian shrub rangelands. Developments to the model (V2) were added to address some short fallings of the original version and allow for a suite of species to be simulated and standing dead material to be included in herbage.

Keywords – plant production, sheep, grazing,

Key contact

Z.G. Yan and K.M. Wang
Western Australian Department of Agriculture

Model status – Technical Report and code for Version 2.1 released in 2003. See point 8.

Ownership/Availability – Fortran code is available in the Technical Report (see point 8)

History of development – the model was initially developed by Dr R. Hacker in 1987 and has since been upgraded to version 2.1 by Z.G. Yan and K.M. Wang.

Hacker, R.B., Wang, K., Richmond, G.S. and Linder, R.K. (1991) IMAGES: An Integrated Model of an Arid Grazing System. *Agricultural Systems*, 37:119-63.

Documentation –

IMAGES Version 2.1
Z.G. Yan and K.M. Wang
Resource Management Technical Report No. 159 (2003)
Western Australian Department of Agriculture
http://agspsrv38.agric.wa.gov.au/pls/portal30/docs/folder/ikmp/lwe/vegt/tr159.pdf

Links to other models – Nil

Objective assessment – see Purpose/Objective

6. LAMSAT
– a model of pasture production, water and erosion systems in the Northern Territory

A. OVERVIEW

Purpose/Objective – LAMSAT was developed to predict animal production and soil erosion for tropical pasture systems in the NT.

Keywords – cattle, production, erosion, runoff, water, land management, tropics

Key contact/s –

Mohammed Dilshad
NT Department of Infrastrucure, Planning and Environment
GPO Box 1680, Darwin, NT 0801

Joe Motha
NT Department of Infrastrucure, Planning and Environment
GPO Box 1680, Darwin, NT 0801

Model status – the LAMSAT model is fully operational, but is not currently being used or developed further by NT DIPE.

Ownership/Availability – the IP for LAMSAT is held by NT DIPE and is available from Mohammed Dilshad or Joe Motha from this NT Department.

History of development – LAMSAT was developed in the early 1990's by Mohammed Dilshad, his departmental colleagues Joe Motha and Luke Peel, and colleagues in CSIRO Soils, NT Department of Primary Industries and Fisheries, and Qld Department of Primary Industries.

Documentation –

The LAMSAT model is described in a NT technical report (Dilshad *et al.* 1994) and in papers published in conference proceedings (Dilshad *et al.* 1996a) and in a scientific journal (Dilshad *et al.* 1996b).

Dilshad, M, Motha, J. A., and Peel, L. J. 1994. Preliminary assessment of the influences of pasture cover on surface runoff, bedload and suspended sediment losses in the Australian semi-arid tropics. *Technical Memorandum No. 94/12*, Conservation Commission of the Northern Territory, Darwin.

Dilshad, M, Motha, J. A., and Peel, L. J. 1996a. Sediment loss and runoff responses to tillage practices in the Douglas-Daly District, Northern Territory. IN: Conservation Farming for the Semi-arid Tropics. (J. D. Sturtz and A. L. Chapman, Eds.). Proceedings of a workshop, Katherine, NT, 18020 July 1995. *AIAS Occasional Publication NO. 101, Darwin*.

Dilshad, M, Motha, J. A., and Peel, L. J. 1996b. Surface runoff, soil and nutrient losses from farming systems in the Australian semi-arid tropics. *Australian Journal of Experimental Agriculture*. 35: 1003-1012.

Links to other models – the LAMSAT model incorporates the GRASP model, but includes soil erosion processes.

Objective assessment – LAMSAT was specifically developed to simulate soil erosion from crop and pasture lands in the Daly Basin of the Northern Territory, and is limited to these ecosystems.

7. LANDASSESS

– a decision support system for sustainable grazing management in northern Australia

A. OVERVIEW

Purpose/Objective – LANDASSESS was developed for the northern Australian beef industry to address issues of spatially dispersed degradation. Increasing use of more watering points, feed supplements, more fences etc. was changing the dynamics of animal usage. LANDASSESS is a DSS that integrates management practices, ecological processes, productivity, seasonal variability, spatial distribution of the biophysical attributes of the management unit, location of infrastructure and financial factors to evaluate the sustainability of a grazing system. LANDASSESS incorporates a GIS, a relational database, process models and a knowledge base system.

Keywords – DSS, grazing, management, sustainability, degradation

Key contact –

Jenny Bellamy
CSIRO Sustainable Ecosystems
306 Carmody Road, St Lucia Qld 4067
Email: *jenny.bellamy@csiro.au*
Tel: (07) 3214 2345

Model status – LANDASSESS is fully operational

Ownership/Availability – IP resides with CSIRO and the NT Department of Local Government and Planning.

History of development – LANDASSESS was developed in the early 1990's for NT government agencies in response to the Pastoral Land Act (1992).

Documentation –

Bellamy, J.A., Lowes, D., Ash, A.J., McIvor, J.G. and MacLeod, N.D. (1996) A decision support approach to sustainable grazing management for spatially heterogeneous rangeland paddocks. *Rangelands Journal* 18: 370-391.

Links to other models – No direct links

Objective assessment –

The major strength of LANDASSESS lies in its integration of biophysical, managerial and economic issues at a scale relevant to the decision makers. The knowledge base component allows users to have considerable input into its development and hence a greater acceptance of it as a tool. However, LANDASSESS has been developed for the Katherine-Douglas region of the NT. While the approach is applicable to other regions of northern Australia, application will be limited by the user's knowledge of the vegetation system of their region in order to develop the necessary state and transition models.

8. MulgaGRASP

- soil water, pasture production, shrub/tree dynamics and greenhouse gas emissions budget model for Australia's mulga rangelands

A. OVERVIEW

Purpose/Objective – GRASP is a 'pasture growth' model that combines a soil water model and a model of above-ground dry-matter flow. It has been built to meet specific objectives relating to grazing management of Australian rangelands: (1) objective assessment of drought and degradation risk in near-real time; (2) simulation of grazing management options including seasonal forecasting; (3) assessment of safe carrying capacity; (4) evaluation of impact of climate change and CO_2 increase; (5) reconstruction of historical degradation episodes; and (6) providing simulations of pasture growth for the industry-supported Grazing Land Management Package. MulgaGRASP has an additional set of modules incorporated into GRASP: (1) replacement of the static tree basal area with a dynamic simulation of shrub/tree seedling establishment, growth and mortality and (2) incorporation of a full greenhouse gas emissions budget dealing with sources and sinks of carbon dioxide, methane and nitrous oxide.

Keywords – soil water, pasture growth, shrub and tree dynamics, greenhouse emissions, climate change risk assessment, grazing land management

Key contact/s –

Mark Howden
CSIRO Sustainable Ecosystems
GPO Box 284, Canberra, ACT, 2601
Email: *Mark.Howden@csiro.au*
Tel: (02) 6242 1679

Greg McKeon – Coordinator (GRASP)
Department of Natural Resources, Mines and Energy
80 Meiers Road, Indooroopilly, Qld 4068
Email: *greg.mckeon@nrme.qld.gov.au*
Tel: (07) 3896 9548

Model status – the model was applied and tested in some case studies several years ago (Moore *et al*. 2001, Howden *et al*. 2001). It has since been tested against other simulation models for the mulga lands and performed creditably. However, further development has not occurred, with the role of MulgaGRASP in performing dynamic simulations of shrub/tree growth taken over by the Golden Wing version of GRASP.

Ownership/Availability – the model is available as a sub-routine based on one-to-one negotiation with the contacts above.

History of development – the modules for shrub/tree dynamics and greenhouse gas emissions were added in 1995-1996. The adjustments required to simulate response to increase in atmospheric concentrations of carbon dioxide and climate change were implemented in 1998.

Documentation – see GRASP description for publications to the underlying GRASP model. For MulgaGRASP:

Howden, S.M., Moore, J.L., McKeon, G.M., and Carter, J.O (2001). Global change and the mulga woodlands of south-west Queensland: greenhouse emissions, impacts and adaptation. *Environment International*, 27: 161-166.

Moore, J.L. Howden, S.M., McKeon, G.M., Carter, J.O., and Scanlan, J.C. (2001) The dynamics of grazed woodlands in south-west Queensland, Australia and their effect on greenhouse gas emissions. *Environment International,* 27: 147-153.

Links to other models – as noted above, MulgaGRASP is a set of sub-models in the GRASP model.

Objective assessment – the strengths of MulgaGRASP are: (1) it uses a validated dynamic simulation of shrub/tree establishment, growth and mortality so that long simulation runs have internally-generated responses of tree-grass competition, productivity, greenhouse emissions etc in response to the interaction of management and climate. This replaced the ‘static’ representation of tree basal area previously in GRASP which was set at a constant value for a given simulation run; and (2) it incorporates a full greenhouse gas budget, calculating the sources and sinks of the major greenhouse gases.

The weaknesses of MulgaGRASP are: (1) the shrub/tree modules were developed specifically for the mulga-lands of semi-arid Australia using limited data sets – they are not designed to be a general solution to this problem; and (2) the limitations of GRASP as described in the relevant section.

9. SEESAW
- Simulation of the Ecology and Economics of the Semi-Arid Woodlands

A. OVERVIEW

Purpose/Objective – SEESAW aims to simulate the sheep production system in the semi-arid woodlands of eastern Australia in order to evaluate the effects of different grazing strategies and climate scenarios on this system.

Keywords – sheep, grazing, production, ecology, economics, management

Key contact/s –

Steve Marsden
[formerly] CSIRO Sustainable Ecosystems
PO Box 284, Canberra, ACT 2602

Ken Hodgkinson
[retired fellow] CSIRO Sustainable Ecosystems
PO Box 284, Canberra, ACT 2602

Model status – the SEESAW model is fully operational, but is not being used or developed further because Steve Marsden has left CSIRO and now works as a private consultant.

Ownership/Availability – the IP for SEESAW resides with CSIRO, which holds a 1998 copyright. SEESAW is available within CSIRO, but using SEESAW is technical and would require the assistance of Steve Marsden.

History of development – SEESAW development began in the late 1980's as part of the Lake Mere sheep grazing trial north of Louth, NSW. The SEESAW model was developed as a research tool to synthesise findings from the grazing trial and to predict the likely ecological and economic outcomes of different grazing strategies and climatic patterns.

Documentation – the features, processes, data sets, parameters, applications and outputs of SEESAW, and the validation and sensitivity of this model, are documented in a report titled: "The SEESAW Model: Simulation of the Ecology and Economics of the Semi-Arid Woodlands". This documentation of the soil water, plant production, sheep management and sheep production submodels of SEESAW was written for the AussieGRASS project in 1998, and is available from this project and from Steve Marsden or Ken Hodgkinson.

Hodgkinson, Ken, Hacker, Ron, Johnston, Peter, and Marsden, Steve. 1996. *Tactical grazing management for maintenance and improvement of wooded rangelands*. Final Report to the International Wool Secretariat on Project CLL36, Melbourne, Vic.

Marsden, Steve and Hodgkinson, Ken. (1998) *The SEESAW Model: Simulation of the Ecology and Economics of the Semi-Arid Woodlands*. CSIRO, GPO Box 284, Canberra, ACT 2602.

Links to other models – the SEESAW model was linked to the GRASP-based AussieGRASS model to evaluate the predictions for the semi-arid mulga woodlands of eastern Australia.

Objective assessment – SEESAW was specifically developed to simulate the ecology and economics of semi-arid woodlands at Lake Mere. Although this model has proven to be more widely applicable to sheep production ecosystems in the mulga woodlands of eastern Australia (e.g., Hodgkinson *et al.* 1996), it should not be extended to systems beyond this region.

10. RANGEPACK Paddock
– paddock planning model for rangelands pastoral properties

A. OVERVIEW

Purpose/Objective – RANGEPACK Paddock allows managers to draw up their paddocks on-screen, then make predictions of likely long-term grazing distribution impacts on the current layout. If these seem credible, then it is a simple process to test the implications of alternative paddock layouts in terms of the locations of fencelines and waterpoints relative to vegetation types and other features. The final versions of the software extended to allow user to keep paddock records and an un-released version was developed to permit stocking distribution decisions to be made among paddocks.

Keywords – grazing distribution, sheep, cattle, large paddocks, rangelands, waterpoint distribution, fence alignment

Key contact/s –

Mark Stafford Smith
Desert Knowledge CRC
PO Box 2111
Alice Springs
NT 0871
08-8950 7162
mark.staffordsmith@csiro.au

Model status – Paddock version 1 was released publicly but only a handful of versions were sold. No further development is currently occurring.

Ownership/Availability – The original IP for the model was held by CSIRO, with elements of development also supported by the National LandCare Program and RIRDC, as well as software sales and workshop fees. Since 1988, the release version has been freely available at cost on a strictly *caveat emptor* basis, only supplied electronically on CD with electronic manuals and some examples. This software is now outdated but is compatible with Windows.

History of development – The original Paddock was developed in a Windows-based shell and released in 1990-92 (ver.1) (actually a simple BASIC version was available prior to this). This version had a sophisticated command language, and enhancements were largely written using this rather than by changing the underlying C code. The core coding of Paddock was mostly carried out by Mark Stafford Smith, with assistance from Monty Sollieux and Michael Hope.

Documentation –

Stafford Smith, D.M., 1988. Modeling: three approaches to predicting how herbivore impact is distributed in rangelands. New Mex.Agr.Sta.Reg.Res. Rep.628, 56pp.

Stafford Smith, D.M. & Foran, B.D. 1988. Practical decision-making: paddock design, economics and land degradation. Poster 5th Austr. Rangel.Conf., Longreach, QLD.

Stafford Smith, D.M. 1991 Planning the use of paddocks in extensive grazing systems: philosophy and practice. Proc.IV Intl.Rangel.Cong., Montpellier, April 1991, 834-836.

Stafford Smith, D.M. & Hope, M.L. 1992. RANGEPACK Paddock Version 1: Users Guide. 70 pp.

Cridland, S., Hope, M., & Stafford Smith, D.M. 1992. Applying an understanding of sheep grazing distribution to paddock design. Proc. 7th Biennial Conf., Austr.Rangel.Soc., Cobar Oct 1992, pp.342-343.

Cridland, S.C. & Stafford Smith, D.M. 1993. Development and dissemination of design methods for rangeland paddocks which maximise animal production and minimise land degradation. *W.A.Dept.Ag.Misc.Publ*. **42**/93.

Links to other models – Paddock was not linked to other models; there are no comparable models available. Some alternative approaches to modelling animal distribution were presented from satellite data by Pickup & Chewings 1988.

Objective assessment – The concepts underlying Paddock are sound, but the computing shell which was built to display them was unduly complex – most of the lessons that could be learned through using the ~100,000 lines of code used for Paddock could be gained from the 500 line BASIC program which proceeded it much less elegantly (though, note, Herd-Econ and Climate were built in the same shell, so the code was not written only for Paddock!). If the program had been developed further to deliver other functions such as paddock stock distributions, etc, the relatively rare planning functions might have found a market on the back of other uses. At the time that Paddock was completed, however, a number of GIS packages which could implement the basic ideas of Paddock more easily were becoming commonly available, although the full functions of Paddock have never been implemented in any GIS shell to our knowledge.

11. Property Safe Carrying Capacity

- safe carrying capacities for pastoral properties in south-west Queensland

A. OVERVIEW

Purpose/Objective – The Property Safe Carrying Capacity model calculates the safe carrying capacity for individual grazing properties in south-western Queensland. It combines a calculation of pasture growth from rainfall use efficiencies with safe pasture utilisation derived from benchmark properties. It has been used to assess 385 properties in the south-west and central-west region from 1995 to 2002. The model was applied in two differing scenarios: (1) voluntary assessments at the request of graziers with the purpose of enhancing their knowledge and understanding of their properties and (2) assessments required as a stage in property reconstruction / amalgamation.

Keywords – property safe carrying capacity, tree density, decision support, pasture growth, woody weeds.

Key contact/s –

Terry Beutel
Department of Primary Industries and Fisheries
PO Box 282
Charleville Q 4470
(07) 4654 4282
terry.beutel@dpi.qld.gov.au

Model status – The model was used during the 1990s as part of the South-West Strategy (a regional adjustment and recovery program). The last property assessments were conducted in September 2002.

Ownership/Availability – Queensland Department of Primary Industries and Fisheries

History of development – Concern at the decline in production (pastures and livestock products) from south-west Queensland has been expressed by a number of authors since the 1930s. To address these concerns a need to review "carrying capacities" / "stocking rates" was suggested by the Warrego Graziers Association (1988), Mills *et al*. (1989), Miles (1989) and Anon. (1993). Development, evaluation and application of this model formed the basis of this review, and was a component of the integrated regional adjustment and recovery program for south-west Queensland termed “The South West Strategy” (Williams 1995).

1986 – 1991 - Field Work
1991 – 1994 - Model development
1995 – Evaluation and application of decision-support package

Documentation –

Anon. (1993) Mulga Region-A study of the inter-dependence of the environment, pastoral production and the economy. A position paper prepared by the Queensland Department of Lands, Brisbane.

Beutel, T.S. (2001) The QDPI Safe Carrying Capacity model: a review of its historical performance in alluvial, wooded alluvial and eucalypt land systems. Queensland Department of Primary Industries, Queensland.

Cooney, D. (1995) Mulga lands carrying capacity survey report. Report to the Queensland Department of Lands, Brisbane.

Crichton, R. (1995) Mulga lands carrying capacity survey report. Report to the Queensland Department of Lands, Brisbane.

Day, K.A., McKeon, G.M. and Carter, J.O. (1997) Evaluating the risks of pasture and land degradation in native pasture in Queensland. Final report for Rural Industries and Research Development Corporation – Project DAQ124A. Queensland Department of Natural Resources, Brisbane.

Johnston, P.W., McKeon G.M. and Day, K.A. (1996) Objective 'safe' grazing capacities for south-west Queensland Australia: Development of a model for individual properties. *Rangeland Journal*, 18: 244-58.

Johnston, P.W., Tannock, P.R. and Beale, I.F. (1996) Objective 'safe' grazing capacities for south-west Queensland Australia: Model application and evaluation. *Rangeland Journal*, 18: 259-69

Johnston, P.W. (1997) Grazing capacity of native pastures in the mulga lands of south-western Queensland: A modelling approach. PhD. Thesis, University of Queensland, St Lucia, Brisbane.

Johnston, P.W., McKeon, G.M., Buxton, R., Cobon, D.H., Day, K.A., Hall, W.B. and Scanlan, J.C. (2000) Managing climatic variability in Queensland's grazing lands – new approaches. In *Applications of seasonal climate forecasting in agricultural and natural ecosystems – the Australian experience*. (Eds G. Hammer, N. Nicholls and C. Mitchell) pp. 197-226. Kluwer Academic Press, Netherlands.

Miles, R.L. (1989) Discussion Paper-Lands Department Review of Carrying Capacity. (Queensland Department of Primary Industries: Charleville).

Mills, J.R., (1989) Management of Mulga Lands in far south - west Queensland. Project Report QO 89023. Queensland Department of Primary Industries, Brisbane.

Mills, J.R., Ahern, C.R., Purdie, R.W. and McDonald, W.J.F. (1990) Western Arid Region Land Use Study. Part 3. Land Resources Technical Bulletin No. 29. Queensland Department of Primary Industries, Brisbane.

Mills, J.R., Turner, E.J., and Caltabiano, T. (1989) Land degradation in south - western Queensland. Project Report QO 89008. Queensland Department of Primary Industries, Brisbane.

Warrego Graziers Association (1988) Submission to the United Graziers Association on the degradation of south-west Queensland.

Williams, R. (1995) South West Strategy, An integrated regional adjustment and recovery program for south west Queensland. Mimeograph, Queensland Department of Primary Industries, Charleville.

Links to other models – The pasture growth model GRASP (Day *et al*. 1997) was used to analyse measurements of pasture growth and provide simulations of average pasture growth. Rainfall-use efficiencies were derived from these simulations.

Objective assessment – The strengths are: (1) the model combines both (a) the science of calculating pasture growth as a function of pasture community, pasture condition, climate, soils and tree density; and (b) safe utilisation rates derived from benchmark properties; (2) a community-supported calculation of sustainable carrying capacity; (3) the successful application of the model using grazier consultants and acceptance by graziers; and, (4) improved producer understanding of carrying capacity through engagement in the assessment process.

The weaknesses are: (1) variability in the relationships between average rainfall and average pasture growth not accounted for e.g. floodplain regions of the channel country.

The limitations are: (1) the relationships are region specific to south-western Queensland.

B. DETAILED MODEL DESCRIPTION

Model features – The model is a spreadsheet calculation using surfaces of rainfall use efficiencies developed for the south-west region. The decision support version includes a paddock by paddock calculation of safe carrying capacity. The model is designed to make a rapid calculation of property safe carrying capacity once a field assessment of individual paddocks has been carried out.

Model processes – The model includes: (a) the calculation of pasture growth as a function of pasture community (land systems from the Western Arid Region land use Studies (Mills *et al*. 1990)), pasture condition, climate, soils and tree density; and (b) safe utilisation rates derived from benchmark properties.

Minimum data sets required – The inputs are average rainfall, pasture community, woody plant density and pasture condition. The user can change estimates of rainfall use efficiency. A field survey methodology has been developed to collect the data inputs to make the calculation of safe carrying capacity.

Parameter sets – The model includes relationships and parameters describing (a) the rainfall use efficiency for different pasture communities; (b) the effect of vapour pressure deficit on rainfall use efficiency across the region; (c) the effect of tree and woody weed density on pasture growth; and (d) safe pasture utilisation rates for individual pasture communities.

Development/Validation data – The model was derived from both field trials and expert opinion in south-western Queensland. The calculation of safe carrying capacity was compared with grazier estimates; 65% of grazier-nominated values were within plus or minus 10% of the calculated safe carrying capacity (Johnston *et al.* 2000).

Sensitivity analyses – Sensitivity studies were conducted as part of simulation studies and presentations to graziers.

Model output – Outputs include: (1) rainfall use efficiency; (2) pasture growth; (3) paddock safe carrying capacity; and (4) property safe carrying capacity.

Application – Various presentations were made to grazier groups. Formal application was made as part of the South-West Strategy on over 280 properties in the region. The results show that safe carrying capacity can be reliably estimated from biophysical assessment of property resources, and that the successful management of benchmark graziers can be extrapolated to other properties using an ecologically bas

12. GRASSMAN

– A Computer Program for Managing Native Pastures in Eucalypt woodlands and calculating carbon stocks and greenhouse gas emission.

A. OVERVIEW

Purpose/Objective – GRASSMAN is a decision support package which looks at the management of eucalypt woodlands in central Queensland, particularly concentrating on tree and regrowth control. The program calculates pasture growth for various tree densities. It also calculates changes in tree basal area in response to grazing and tree management. A version has been developed which includes a budget of the key sources and sinks of the major greenhouse gases carbon dioxide, methane and nitrous oxide (Howden et al. 1994).

Keywords – tree growth, decision support, pasture growth, eucalypt woodlands, safe carrying capacity, greenhouse gas emissions, carbon stocks.

Key contact/s –

Joe Scanlan
Robert Wicks Pest Animal Research Centre
Natural Resources, Mines and Energy
Toowoomba Qld 4350
Email: *Joe.Scanlan@nrm.qld.gov.au*
Tel: (07) 4688 1243

Mark Howden
CSIRO Sustainable Ecosystems
GPO Box 284
CANBERRA ACT 2601
Mark.Howden@csiro.au

Greg McKeon
Department of Natural Resources, Mines and Energy
(07) 3896 9548
greg.mckeon@nrme.qld.gov.au

Jeff Clewett, Program coordination
Michael Whelan, Software
Ken Day, Help notes
Ian Partridge, Users guide
Bill Burrows, Woodland and pasture specialist
Eric Anderson, Woodland and pasture specialist
Col Paton, Woodland and pasture specialist
Russ Tyler, Field evaluation
Phil Anning, Field evaluation

Model status – The model has been archived, although many of the relationships developed are part of current model development.

Ownership/Availability – The decision-support package was available from Queensland Department of Primary Industries. Preliminary FORTRAN code held by Joe Scanlan and Greg McKeon. PASCAL code for carbon stocks and greenhouse gas emissions is held by Mark Howden.

History of development –

1989 – Model development

1990 – Release of decision-support package
1990 – Greenhouse gas emission model development

Documentation –

Clewett, J.F., Cavaye, J.M., McKeon, G.M., Partridge, I.J. and Scanlan, J.C. (1991). Decision support software as an aid to managing pasture systems. *Tropical Grasslands* **25**: 159-164

Howden, S.M., McKeon, G.M., Scanlan, J.C., Carter, J.O. and White, D.H. (1993). Changing stocking rates and burning management to reduce greenhouse gas emissions from northern Australian grasslands. *XVII International Grassland Congress Palmerston North, New Zealand*. pp. 1203-5

Howden, S.M., McKeon, G.M., Scanlan, J.C., Carter, J.O., White, D.H. and Galbally, I.E. (1992). Managing pastures in northern Australia to minimise greenhouse gas emissions. *Proceedings of an IPCC Workshop Assessing technologies and management systems for Agriculture and Forestry in relation to Global Climate Change*. Canberra, Australia, Australian Government Publishing Service. pp 61-67

Howden, S.M., McKeon, G.M., Scanlan, J.C., Carter, J.O., Galbally, I.E. and White, D.H. (1991). Managing pastures in northern Australia to minimise greenhouse gas emissions: adaptation of an existing simulation model. *Ninth Biennial Conference on Simulation and Modelling*. pp. 168-178

Scanlan, J.C. and McKeon, G.M. (1990). GRASSMAN – a computer program for managing native pastures in eucalypt woodland. *Queensland Department of Primary Industries, Brisbane.*

Scanlan, J.C. and Burrows, W.H. (1990). Woody overstorey impact on herbaceous understorey in *Eucalyptus* spp. Communities in central Queensland. *Australian Journal of Ecology.*

Burrows, W.H., Carter, J.O., Scanlan, J.C. and Anderson, E.R. (1990). Management of savannas for livestock production in north–east Australia: contrasts across the tree–grass continuum. *Journal of Biogeography* 17: 503–12.

Links to other models – An experimental version of GRASSMAN was linked to herd dynamics model HerdEcon (Mark Stafford Smith).

Objective assessment – The strengths are: (1) the model and parameters capture the expert knowledge of the behaviour of a number of eucalypt woodland communities including the effects of grazing and tree management options; (2) provided the basis for latter model development (Johnston 1996, McKeon *et al.* 2000, Scanlan and McKeon 1993); provided for the calculation of management effects on greenhouse gas emissions.

The weaknesses are: (1) the lack of a detailed economic analysis of the implications of these options; (2) 6 monthly time step limits model dynamics; and (3) only 15 years are simulated.

The limitations are: (1) the relationships are region specific to central Queensland; (2) a full economic cash flow analysis is required; (3) *Acacia* overstories are not included; and (4) relationships of animal production as a function of stocking rate were based on small area grazing trials. The limitations were addressed in subsequent developments of GRASP.

B. DETAILED MODEL DESCRIPTION

Model features – The model was initially written in FORTRAN. The DSS version was written in PASCAL to run on PCs in the early 1990s. The decision support version includes graphical output and extensive help notes written by K.A. Day. The carbon stock-greenhouse gas emission version was written in PASCAL by Mark Howden.

Model processes – The model includes: (1) the dynamics of changes in tree basal area as a result of different management options; and (2) sub-models of pasture growth, yield and grass basal area and animal liveweight gain. A six-monthly timestep is used for 15 years. Climate variability can be entered by the user using five year-types to provide variability in pasture growth. The calculation of tree basal area on pasture growth comes from the general model proposed by Scanlan and Burrows (1990) for central Queensland.

Carbon stocks and greenhouse gas emissions are calculated by using models developed by Howden *et al.* (1991, 1992).

Minimum data sets required – The user inputs average seasonal rainfall, eucalypt community and the user can change estimates of pasture growth and animal production. The lifetime of various tree management options can also be changed by the user.

Parameter sets – The model includes parameters describing the dynamics of changes in tree basal area as well as pasture growth and animal production for central Queensland pasture communities.

Development/Validation data – The model was derived from both field trials and expert opinion in Central Queensland. The impacts of tree competition on pasture growth was described in Scanlan and Burrows (1990). The relationship between pasture growth, stocking rate and animal production was described in Rickert and McKeon (1984) and the Galloway Plains stocking rate trial (Burrows *et al.* pers. com.). Grass basal area change is calculated as function of climate and utilisation was derived from the field data of Scattini (1973) and was described in McKeon *et al.* (1990).

Greenhouse gas emissions were calculated from relationships developed from the scientific literature (Howden *et al.* 1991, 1992).

Sensitivity analyses – Sensitivity studies were conducted as part of simulation studies and presentations to graziers.

Model output – Outputs include: (1) tree stand dynamics in terms of tree basal area; (2) tree height; (3) pasture growth and standing dry matter; (4) grass basal area expressed as pasture condition; (5) animal production; (6) carbon studies; and (7) greenhouse gas emissions.

Application – Various presentations were made to grazier groups. Formal simulations were reported in Clewett *et al.* (1991) and Howden *et al.* (1991, 1992, 1993). Major outcomes were: (1) a calculation of carbon stocks and greenhouse gas emissions for different tree and pasture management scenarios (Howden *et al.* 1991, 1992, 1993); (2) the calculation of safe carrying capacity (Scanlan *et al* 1994, Johnston 1996) and the potential value of changing stocking rate in response to climate forecasting (leading to McKeon *et al.* 2000).

Clewett, J.F., McKeon, G.M., Scanlan, J.C., Taylor, W.J. and Rickert, K.G. (1991). BEEFMAN: A series of decision support and educational software for the beef industry of north Australia. *Proceedings of the International Conference on Decision Support Systems for Resource Management,* April 1991, (Texas A&M University, College Station, Texas, U.S.A.) pp 15-18

Howden, S.M. and McKeon, G.M. (1992). Methane emissions in agricultural and grazing systems. In `*Greenhouse Impact on Rural Industry*'. Australian Institute of Agricultural Science. *Occasional Publication* No. 66. pp. 22-28

Howden, S.M., White, D.H., McKeon, G.M., Scanlan, J.C. and Carter, J.O. (1994). Methods for exploring management options to reduce greenhouse gas emissions from tropical pastures. *Climate Change*, 30: 49-70

Howden, S.M., White, D.H., McKeon, G.M., Scanlan, J.C. and Carter, J.O. (1994). Methods for exploring management options to reduce Greenhouse gas emissions from tropical grazing systems. *Climatic Change* **27:** 49-70

McKeon, G.M. and Howden, S.M. (1992). Adapting the management of Queensland's grazing systems to climate change. In `*Climate Change: Implications for Natural Resource Consideration*'. University of Western Sydney, Hawkesbury. *Occasional Paper* No. 1. pp. 123-40

McKeon, G.M., Day, K.A., Howden, S.M., Mott, J.J., Orr, D.M., Scattini, W.J. and Weston, E.J. (1990). Management of pastoral production in northern Australian savannas. *Journal Biogeography*. **17**: 355-72

Rickert, K.G. and McKeon, G.M. (1984). A computer model of the integration of forage options for beef production. *Proceedings Australian Society Animal Production*. **15**: 15-19

Scanlan, J.C., Mott, J.J., McKeon, G.M., Day, K.A. and Lawes, D. (1990). Predicting Outcomes of management decisions in grazed native grasslands. In: P.M. Dowling and D.L. Garden (Eds) `*Native Grass Workshop Proceedings*'. NSW Agriculture and Fisheries and Australian Wool Corporation, Dubbo, October 1990. pp. 59-70

Scanlan, J.C., McKeon, G.M., Day, K.A., Mott, J.J. and Hinton, A.W. (1994). Estimating safe carrying capacities of extensive cattle grazing properties within tropical semi-arid woodlands

Category 4 - These are models not directly designed for rangeland use but are being used or can be used in the rangelands

1. APSIM

- Agricultural Production Systems sIMulator

A. OVERVIEW

Purpose/Objective – APSIM has been developed by the **A**gricultural **P**roduction **S**ystems **R**esearch **U**nit. APSRU's primary challenge is to provide insight and information about natural resource, crop and soil management of farming systems that assists producers, their advisors, agribusiness, natural resource planners, and government. Such information aims to improve technical and economic efficiency in the interests of competitiveness without jeopardising the ecological stability of farming systems. APSIM is a core technology of the Unit's applied research and development.

Keywords – crops, cropping systems, farming systems

Key contact –.
Dr Peter Carberry
CSIRO Sustainable Ecosystems
203 Tor St, Toowoomba, Qld 4350
Email: *Peter.Carberry@csiro.au*
Tel: (07) 4688 1200

Model status – the model is fully operational, but under continuing development as new modules are added to the APSIM modelling framework.

Ownership/Availability – APSIM is owned by APSRU, a joint research unit of Queensland Departments of Primary Industries & Fisheries (DPI) and Natural Resources, Mines & Energy (DNRM), CSIRO's Divisions of Sustainable Ecosystems (CSE) and Land & Water (CLW), and the University of Queensland (UQ). APSIM is available under licence from APSRU.

History of development – Development of APSIM began in 1990 and continues. APSIM now contains modules for Wheat, Maize, Sorghum, Millet, Rice, Canola, Sunflower, Cotton, Lucerne, Chickpea, Peanut, Mungbean, Fababean, Navybean, Soybean, Pigeon Pea, Cowpea, Lupin, Mucuna, Sugarcane, Bambatsi, Pasture grass, Stylo, Weeds, Plantation forest, Root parasite, Residues and Manure, Nitrogen and Phosphorous dynamics and response, Fertiliser, Irrigation, Water storage and Tillage, Erosion and two water balance modules including solute movement. It allows rotations, dynamic management and decision making, management of and interaction between multiple adjacent sites, and species competition for resources through 'intercropping'. Version 3.5 was released on 13th April 2004. A fully functional demonstration installation is available from the download website - http://www.apsim.info/apsim/Downloads.

Documentation – full documentation is available and limited support from APSRU. Much information is available on the web at *http://www.apsru.gov.au/apsru/Default.htm*

Links to other models – The modular framework of APSIM allows other models to be incorporated into APSIM e.g. Swim, Grasp, Ozcot. Output from APSIM is utilised in many other models.

Objective assessment – APSIM is a modelling framework.

Strengths

One of the main benefits, and also one of the most important design specifications, is the ability to integrate models derived in fragmented research efforts. This enables research from one discipline or domain to be transported to the benefit of some other discipline or domain. It also facilitates comparison of models or sub-models on a common platform.

This functionality has been achieved via the implementation of a "plug-in-pull-out" approach to design. APSIM has been developed in a way that allows the user to configure a model by choosing a set of sub-models from a suite of crop, soil and utility modules. Any logical combination of modules can be simply specified by the user "plugging-in" required modules and "pulling out" any modules no longer required.

Weaknesses

Although APSIM will allow the coupling of models from separate research efforts, it is up to the designers and users of the sub-model to ensure that it will operate correctly as a component of the system in conjunction with other APSIM modules. Due to the complexity of APSIM, considerable training is required before a user can become efficient in its use. There are no animal production modules and pasture simulation is achieved through a linkage to GRASP, which has not been calibrated for introduced pasture grasses and legumes.

2. GRASSGRO

– a pasture, animal and economic model for temperate regions.

A. OVERVIEW

Purpose/Objective - GrassGro is a decision support tool developed by CSIRO Plant Industry to examine variability in pasture and animal production and analyse profit, risk and sustainable use of resources so as to assist decision-making in temperate climate sheep and beef enterprises. By testing management options against a wide range of seasons, farmers and natural resource managers explore whether they can achieve more profitable and sustainable utilisation of grasslands to fit the unique combination of weather, soils, pastures and livestock at a particular location. GrassGro can be applied to a broad range of issues in agriculture and natural resource management at both farm and regional scale:

- Assessment of land capability and production benchmarking
- Resource sustainability: ground cover, water balance, nutrient deficiency
- Drought management
- Testing the suitability of pasture types, animal bloodlines and enterprises at a location
- Testing strategic and tactical decisions before committing funds: lambing and calving dates, supplementary feed policy, market specifications for livestock and more
- Supply chain analysis

Keywords - grazing sheep and beef cattle productivity, temperate pastures, pasture growth, intake, nutrition, liveweight

Key contact

John Donnelly
CSIRO Plant Industry
GPO Box 1600, Canberra, ACT, 2601
Email: *John.Donnelly@csiro.au*
Tel: (02) 6246 5106

Model status - the model is fully operational.

Ownership/Availability - the model is commercially available via Horizon Software and comes with user guide and documentation. Some data elements are available in the model whilst a few are documented in publications.

History of development - GrassGro was released in the early 1990s. The key developers were staff of CSIRO Plant Industry. The history of the GRAZPLAN components is documented in:

Donnelly J.R., Freer M, Salmon L, Moore AD, Simpson RJ, Dove H, Bolger TP (2002) Evolution of the GRAZPLAN decision support tools and adoption by the grazing industry in temperate Australia. *Agricultural Systems*, 74: 115-139.

Documentation

Donnelly JR, Moore AD, Freer M (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises .1. Overview of the GRAZPLAN project, and a description of the MetAccess and LambAlive DSS. *Agricultural Systems*, 54: 57-76.

Freer M, Moore AD, Donnelly JR (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises .2. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems* 54: 77-126.

Moore AD, Donnelly JR, Freer M (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises .3. Pasture growth and soil moisture submodels, and the GrassGro DSS, *Agricultural Systems*, 55: 535-582.

Clark SG, Donnelly JR, Moore AD (2000). The GrassGro decision support tool: its effectiveness in simulating pasture and animal production and value in determining research priorities. *Australian Journal of Experimental Agriculture*, 40: 247-256.

Cohen RDH, Stevens JP, Moore AD, Donnelly JR (2003) Validating and using the GrassGro decision support tool for a mixed grass/alfalfa pasture in western Canada. *Canadian Journal of Animal Science*, 83: 171-182.

Links to other models - GrassGro is one component of the Grazplan Decision Support System (Donnelly *et al.* 1997) for temperate Australian grazing lands. GrassGro couples the Grazplan feed intake and ruminant nutrition models with a daily simulation model of pasture growth and dynamics. The pasture growth module is quite general in structure but recognises four functional groups of pasture plants: annual and perennial species are distinguished, as are grasses and forbs. Shoot tissue is classified as live, senescing, standing dead, or litter, and also according to ifs dry matter digestibility, thus enabling potential integration with diet selection and feed intake models. GrassGro is also linked to the APSIM modelling framework (Keating *et al.* 2000) via the CSIRO Common Modelling Protocol. This allows GrassGro to interact with the numerous crop, tree and pasture modules in APSIM.

Objective assessment

GrassGro is a comprehensive model drawing off a large amount of research on animal intakes, nutrition and performance coupled with a soundly-based model of soil-pasture interactions. It has been constructed and tested with a focus on temperate pastures, particularly in south-east Australia. There has been limited testing in tropical and semi-arid to arid systems, with some indication that the animal intake and performance components work less well in these environments. Limitations of GrassGro were identified (parameter sets not available for some pasture species, inability to simulate clumpy swards, rudimentary interspecies competition model) and some improvements were made to its performance (improved species parameter sets and improved modeling of rooting depth). Recommendations are made on priority areas of research to improve GrassGro and on improvements in methodology which could be adopted by future programs like Temperate Pasture Sustainability Key Program. Due to the focus on temperate pastures, GrassGro does not have some of the components that can be important in rangelands models such as tree/shrub components, fire management. Nor is it clear how effectively it would deal with the periods of extended drought that occur in the rangelands. It is also not currently set up to make analyses of the capacity of seasonal climate forecasts to improve management although it presents results in probabilistic form based on the full historical climate record. There would be a moderate to large amount of work required to develop the components of a more comprehensive rangelands model and to test the soil, pasture and livestock components of the model for such environments. An alternative approach may be to incorporate GrassGro routines into other rangeland models.

Clark *et al*. (2000) addressed the limitations of GrassGro (parameter sets not available for some pasture species, inability to simulate clumpy swards, rudimentary interspecies competition model) making some improvements to its performance (improved species parameter sets and improved modelling of rooting depth). They made recommendations on priority areas of research to improve GrassGro and on improvements in methodology which could be adopted by future programs like the Temperate Pasture Sustainability Key Program.

3. Arid River Flow

- model of floodplain river flows in the arid zone

A. OVERVIEW

Purpose/Objective - transmission losses of ephemeral and intermittent rivers in the arid zone have major consequences for water resources and ecological responses of the river system. In turn, this impacts on the vegetative growth and resources for arid zone fauna. This model was developed to characterise a 330km reach of the Diamantina river in south-west Queensland.

The model uses a grid cell system of 0.05 X 0.05 degrees and runs at a daily time-step. Inputs include stream flows measured from gauging stations, interpolated daily rainfall and monthly mean evaporation values. Path flows (routing) between grid cells are explicitly defined from topographic maps. Three land types classes are used: primary and secondary channels, and the rest of the catchment.

Keywords – floodplain, river flow, landscape, topography, path flows

Key contact/s

J.F.Costelloe
CRC for catchment Hydrology
Dept. of Civil and Environmental Engineering
University of Melbourne, Victoria 3010
Email: *j.costelloe@civag.unimelb.edu.au*
Tel: (03) 8344 7238

South Australian Dept of Water Land and Biodiversity Conservation (ARIDFLO project)

Model status – model is still under development

Ownership/Availability – this model is part of a collaborative project (ARIDFLO), between the South Australian Dept of Water Land and Biodiversity Conservation, Queensland Environmental Protection Agency/Parks and Wildlife Service, and Queensland Dept natural Resources and Mines and the work is associated with the CRC for Catchment Hydrology

History of development – results of the modelling work were published in 2003 (see Costelloe *et al*. 2003). The model was calibrated on data for 2 periods, 1973-80 and 1979-86. The model was constructed using the Catchment Simulation Shell developed by the CRC for Catchment Hydrology.

Documentation –

Costelloe, J.F., Grayson, R.B., Argent, R.M. and McMahon, T.A. (2003) Modelling the flow regime of an arid zone floodplain river, Diamantina River, Australia. *Environmental Modelling & Software* 18, 693-703.

Links to other models – none

Objective assessment -

Strengths

- the use of the grid-based concept shows considerable promise over whole basin type models

- the approach allows for 2 critical factors in estimating transmission losses: explicit representation of routing and spatial distribution of flooding; and the influence of different land types on soil water storage and routing parameters

Weaknesses

- needs additional information to constrain the modelling of the deep infiltration process
- the model need the capability for switching of cell connectivity at threshold flow volumes

4. CLIMEX

- a dynamic simulation model to predict the potential geographical distribution of a species, plant or animal

A. OVERVIEW

Purpose/Objective – Computer-software for predicting the potential distribution and relative abundance of species in relation to climate. CLIMEX is currently used in over twenty countries to examine the distribution of insects, plants, pathogens and vertebrates for a variety of purposes, including biogeography, quarantine, biological control and impacts of changes in climate and climate variability.

Keywords – climate, distribution, species abundance

Key contact –
CLIMEX Support
CSIRO Entomology
120 Meiers Road, Indooroopilly, Qld 4068
Email: *CLIMEX@csiro.au*
Tel: (07) 3214 2707 or 3214 2800
Fax: (07) 3214 2885

Model status - the software is fully developed and operational

Ownership/Availability – IP is held by CSIRO Entomology. The software is available for purchase from CSIRO Publishing, PO Box 1139, Collingwood, Victoria 3066 (email: *sales@publish.csiro.au*). Demo versions can be viewed on the web.
http://www.ento.csiro.au/research/pestmgmt/IPMModellingNetwork/software2.htm

History of development – this program was developed by CSIRO Entomology in 1985 and has had numerous successful applications under practical conditions.

Documentation – extensive user documentation and support are available from CSIRO; training workshops are held regularly.

Links to other models – CLIMEX has been developed using the DYMEX software; out put can be exported into Arcview.

Objective assessment – CLIMEX uses minimal data sets and simple functions to describe the species' response to temperature and moisture, using Compare Locations or Compare Years options. A "Growth Index" (GI) describes the potential for growth of a population during the favourable season, and four stress indices (Cold, Hot, Wet and Dry) describe the probability of the population surviving through the unfavourable season. The GI and Stress Indices are combined into an "Ecoclimatic Index", EI, to give an overall measure of favourableness of the location or year for a species. The results can be presented as tables, graphs or maps.

CLIMEX includes a climate-matching function that can be used in the absence of any knowledge of the distribution of a species. The Match Climates option allows the user to directly compare the temperature, rainfall, rainfall pattern and relative humidity of a given location with any number of other locations. It provides a method of identifying sites with similar climates for targeting collection and release sites, or for assessing risks from exotic species. Weighting and masking functions allow the user to select variables for modelling (e.g. temperature) or to choose particular months that need to be used in a comparison (e.g. summer months in temperate zones).

5. IHACRES

– rainfall and run-off model

A. OVERVIEW

Purpose/Objective – the primary purpose of the model is for simulating the influence of climate, and land use changes on streamflow generation, as well as extending the observed record of streamflow and filling in gaps in recorded data. The model is also able to separate observed flow into quick and slowflow components. The model needs to be calibrated at gauged sites, though predictions at ungauged sites can be made through determination of regional relationships between catchment attributes and the model parameters.

Keywords – rainfall-runoff, climate change, land use impacts, baseflow separation, regionalisation

Key contact/s –

Dr Barry Croke
Australian National University
Email: *Barry.Croke@anu.edu.au*

Model status – Java version of IHACRES is currently in the beta testing phase. Will be officially released on the Catchment Modelling Toolkit website.

Ownership/Availability – software will be freely available when installed on Catchment Modelling Toolkit website. Until then, the software can be obtained from Barry Croke.

History of development – the original software was developed by The Australian National University and the Institute of Hydrology in Wallingford, UK (now the Centre for Ecology and Hydrology). A detailed description can be found in Jakeman, Littlewood and Whitehead (1990) and Jakeman and Hornberger (1993). The original model has been modified by several authors, including Ye et al (1997 - inclusion of a threshold and non-linear relationship in the original version) and most recently Croke and Jakeman (1994 – development of the Catchment Moisture Deficit version). The key developers of the Java version have been Barry Croke, Tony Jakeman and Felix Andrews.

Documentation – published papers include:

Model development

Jakeman, A.J. and G.M. Hornberger (1993) How much complexity is warranted in a rainfall-runoff model? *Water Resources Research* 29, 2637-2649.

Jakeman, A.J., Littlewood, I.G. and Whitehead, P.G. (1990) Computation of the instantaneous unit hydrograph and identifiable component flows with application to two small upland catchments. *Journal of Hydrology*, 117, 275-300.

Ye, W., B. Bates, N. R. Viney, M. Sivapalan and A. J. Jakeman (1997). Performance of conceptual rainfall-runoff models in low-yielding ephemeral catchments. *Water Resources Research* 33, 153-166.

Croke, B. F. W. and A. J. Jakeman (2004). A Catchment moisture deficit module for the IHACRES rainfall-runoff model. *Environmental Modelling and Software* 19, 1-5.

Applications

Dye, P.J. and B.F.W. Croke (2003) Evaluation of Streamflow Predictions by the IHACRES Rainfall-Runoff Model in Two South African Catchments. *Environmental Modelling and Software*, 18, 705-712.

Evans, J.P. and A.J. Jakeman (1998) Development of a simple, catchment-scale, rainfall-evapotranspiration-runoff model. *Environmental Modelling and Software* 13, 385-393.

Hansen, D. P., A. Jakeman, C. Kendall and G. Weizu (1997) Identification of internal flow dynamics in two experimental catchments. *Mathematics and Computers in Simulation* 43, 367-375.

Hansen, D. P., W. Ye, A. J. Jakeman, R. Cooke and P. Sharma (1996) Analysis of the effect of rainfall and streamflow data quality and catchment dynamics on streamflow prediction using the rainfall-runoff model IHACRES. *Environmental Software* 11, 193-202.

Kokkonen, T. S. and A. J. Jakeman (2001) A comparison of metric and conceptual approaches in rainfall-runoff modelling and its implications. *Water Resources Research* 37, 2345-2352.

Kokkonen, T. S. and A. J. Jakeman (2002). Structural effects of landscape and land use in streamflow response.Chapter 14: In *Environmental Foresight and Models* A. Manifesto and M. B. Beck.(Eds), Amsterdam, Elsevier pp. 303-321

Kokkonen, T. S., Jakeman, A.J., Young P.C. and Koivusalo, H.J. (2003) Predicting daily flows in ungauged catchments: model regionalization from catchment descriptors at the Coweeta Hydrologic Laboratory, North Carolina. *Hydrological Processes* 17, 2219–2238.

Letcher, R. A., B. F. Croke and A. J. Jakeman (in press). Model Development for Integrated Assessment of Water Allocation Options. *Water Resources Research*.

Littlewood, I.G. (2002) Improved unit hydrograph characterisation of the daily flow regime (including low flows) for the River Teifi, Wales: towards better rainfall-streamflow models for regionalisation. *Hydrology and Earth System Sciences*, 6, 899-911.

Merritt, W. S., B. F. Croke, A. J. Jakeman, R. A. Letcher and P. Perez (2004). A biophysical toolbox for assessment and management of land and water resources in rural catchments in Northern Thailand. *Ecological Modelling* 171, 279-300.

Post D.A. and A.J. Jakeman (1996) Relationships between catchment attributes and hydrological response characteristics in small Australian mountain ash catchments. *Hydrological Processes* 10, 877-892.

Post, D. A. and A. J. Jakeman (1999). Predicting the daily streamflow of ungauged catchments in S.E. Australia by regionalising the parameters of a lumped conceptual rainfall-runoff model. *Ecological Modelling* 123, 91-104.

Post, D. and A. J. Jakeman (1996). Relationships between catchment attributes and hydrological response characteristics in small Australian mountain ash catchments. *Hydrological Processes* 10, 877-892.

Post, D. and A. J. Jakeman (1998). Using a lumped conceptual rainfall-runoff model to predict the hydrologic impact of forestry treatments. *Canadian Water Resources Assoc. 51st Conference*, Victoria, Canada,10-12 June 1998. Y. Alila.(Eds).

Post, D., A. J. Jakeman, I. G. Littlewood, P. G. Whitehead and M. D. A. Jayasuriya (1996) Modelling land cover induced variations in hydrologic response: Picaninny Creek, Victoria. *Ecological Modelling* 86, 177-182.

Schreider, S. Y., A. J. Jakeman and A. B. Pittock (1996) Modelling rainfall-runoff relationships from catchment to basin scale: the Goulburn Basin. *Hydrological Processes* 10, 863-876.

Schreider, S. Y., A. J. Jakeman, A. B. Pittock and P. Whetton (1996) Estimation of possible climate change impacts on water availability, extreme flow events and soil moisture in the Goulburn and Ovens Basins, Victoria. *Climatic Change* 34, 513-546.

Schreider, S. Y., A. J. Jakeman, R. A. Letcher, R. J. Nathan, B. Neal and S. G. Beavis (2002) Detecting changes in streamflow response to changes in non-climatic catchment condition: farm dam development in the Murray-Darling Basin, Australia. *Journal of Hydrology* 262, 84-98.

Schreider, S. Y., D. I. Smith and A. J. Jakeman (2000) Climate change impacts on urban flooding, 2000. *Climatic Change* 47,91-115.

Schreider, S. Y., P. Whetton, A. Jakeman and A. B. Pittock (1997) Runoff modelling for snow-affected catchments in the Australian Alpine Region, Eastern Victoria. *Journal of Hydrology* 200, 1-23.

Ye, W., A. J. Jakeman and C. Barnes (1995) A parametrically efficient model for prediction of streamflow in an Australian benchmark catchment with complex storage dynamics. *Environment International* 21, 539-544.

Ye, W., A. J. Jakeman and P. C. Young (1998) Identification of improved rainfall-runoff models for an ephemeral low-yielding Australian catchment. *Environmental Modelling and Software* 13, 59-74.

Ye, W., D. P. Hansen, A. J. Jakeman, P. Sharma and R. Cooke (1997) Assessing the natural variability of runoff: Clarence Basin catchments, NSW Australia. *Mathematics and Computers in Simulation* 43, 251-260.

Links to other models – the IHACRES model has been used in a number of integrated catchment studies. This includes linking the model to the CATCHCROP model for simulating the effects of land use change, the STARS contaminant transport model, as well as economic decision making models. In addition, the model has been linked to the groundwater discharge model of Sloan (2000). A simulation version of the model (excluding the simple refined instrumental variable (SRIV) calibration software) has been coded within ICMS (Integrated Component Modelling System). Ye et al (1997) compared the performance of the IHACRES model with the Generalized Surface inFiltration Baseflow (GSFB) model and the Large Scale Catchment Model (LASCAM). A more general comparison of a large number of model structures on 429 catchments from across the globe was carried out by Perrin *et al*. (2001).

Ye, W., Bates, B. C., Viney, N. R., Sivapalan, M., Jakeman, A. J. (1997). Performance of conceptual rainfall-runoff models in low-yielding ephemeral catchments. *Water Resources Research*, 33, 153-166.

Perrin, C., Michel, C., Andreassian, V. (2001). Does a large number of parameters enhance model performance? Comparative assessment of common catchment model structures on 429 catchments. *Journal of Hydrology*, 242, 275-301.

Objective assessment –

The main strength of the IHACRES model is that relatively few parameters (typically 5-7) need to be estimated. Aside from ease of calibration, this also aids in applying the model to regionalisation studies. The advantages of the Java version of IHACRES include: improved data visualisation tools, additional goodness of fit indicators, inclusion of more recent developments in the model structure (currently, the extended non-linear module developed by Ye et al. has been included, and the CMD version will be included shortly).

The main weakness of the model is its lumped nature. Typical applications use one set of parameters for an entire catchment (exception is a stand-alone version being developed - see Carlile et al. 2002). This means that influence of spatial variation within the catchment (e.g. location of forests) cannot be modelled.

Carlile, P. W., A. J. Jakeman, B. F. Croke and B. G. Lees (2002). Use of catchment attributes to identify the scale and values of distributed parameters in surface and sub-surface conceptual hydrology models. *Proceedings International Environmental Modelling and Software (iEMSs) Biennial Conference, Lugano, Switzerland,24-27 June 2002*. A. E. Rizzoli and A. J. Jakeman.(Eds). vol. 1 pp. 346-351

6. IQQM
- Integrated Quantity and Quality Model

A. OVERVIEW

Purpose/Objective – IQQM is a hydrological modelling tool designed to investigate the impacts of water resource management policy or policy change on stakeholders by simulating how much water makes its way though a given river system and what proportion of flow is lost from the system. The model is a shell used to link a suite of model components including surface runoff generation, instream water quantity and quality (particularly salinity). IQQM operates on a daily time step (shorter intervals are also possible if required) and is capable of simulating river behaviour for extended time periods (hundreds of years).

IQQM functionality is particularly strong in management of large scale regulated river systems with large headwater storages and very complex river management, operational, water accounting, allocation and sharing rules, including environmental management components. IQQM was conceived very much for Australian river systems with high climate variability and long travel times. Specific IQQM models are in current use by New South Wales and Queensland governments for management of all major irrigated river systems.

IQQM has also been implemented in the Mekong River Basin, Lombok (Indonesia) Irrigation area, and is currently being implemented by the MDBC in the Murray River System. IQQM is the key link in translating inputs from catchment salt mobilisation models in the NSW and Qld Murray Darling Basin to end-of valley salinity target sites

Keywords – water quality, water quantity, irrigation model, reservoir model, routing, resource management, policy, environmental flows

Key contact/s –
Mr Paul Pendlebury
Manager, Surface and Groundwater Processes
NSW Department of Infrastructure, Planning and Natural Resources
Email: *Paul.Pendlebury@dipnr.nsw.gov.au*

Model status – the model is fully operational and is distributed with a graphical user interface, manuals and training material. The model is under constant development to meet the emerging needs of water managers. The development is largely supported with DIPNR.

Ownership/Availability – IQQM was developed by Centre for Natural Resources, NSW Department of Land and Water Conservation (currently NSW Department of Infrastructure, Planning and Natural Resources). IP for IQQM is vested in DIPNR. The executable version is available with documentation via a licence. A number of partnership/collaboration arrangements are in place, whereby high level access is available for module development and sharing between users.

History of development – IQQM development was initiated in the early 1990's and has been under continuous development since that time. The Windows version is currently available.

Documentation – a model description is available through the Centre for Natural Resources, NSW Department of Infrastructure, Planning and Natural Resources (*http://www.dlwc.nsw.gov.au/care/water/pdfs/iqqm1999.pdf*)

Links to other models – IQQM has linkages with a number of rainfall runoff models (eg SACRAMENTO) and an interface with the proprietary MODFLOW software. It has also been linked to the hydrodynamic software RUBICON for representing conveyance through a complex wetland system. It is linked with the Water Reallocation Model (WRAM) to model aspect of temporary and permanent water trade within basins.

Objective assessment – the IQQM framework is currently used by the NSW Department of Infrastructure, Planning and Natural Resources. It is the core hydrologic planning model for addressing all resource management issues, preparing water sharing plans, and translating salinity impacts of landscape change to reflect accountability under the Murray Darling Basin Salinity Management Strategy.

7. APLC DSS

- Australian Plague Locust Commission Decision Support System for locust control

A. OVERVIEW

Purpose/Objective – the APLC DSS consists of a number of models and modules designed for use by APLC staff as an aid in the forecasting and control of locust outbreaks. The DSS is based on a Geographic Information System that integrates data on weather and habitat condition with the migration, development and distribution of the pest to prepare forecasts and decisions for control. Daily rainfall and temperature information is collected from Bureau of Meteorology (BoM) as both gridded data and reported records. Grass response is confirmed by NDVI satellite imagery. A wind trajectory model as developed by Rochester et al (1996: Ecological Modelling 86: 151-156) is used to produce a map of where insects in various locations might have gone if they had migrated on a particular night. The generic population modelling software Dymex (CSIRO) uses rainfall (via soil moisture and grass response) and temperature data obtained directly from the BoM databases to estimate locust development and survival at a large number of sites in eastern Australia. Data from locust surveys and reports is used to confirm or update forecasts so that control decisions can be made using the most recent data.

Keywords – locusts, rangeland, development, decision support

Key contact/s –
Ted Deveson (*ted.deveson@daff.gov.au*) or
David Hunter (*david.hunter@daff.gov.au*)
Australian Plague Locust Commission
Department of Agriculture Fisheries and Forestry,
GPO Box 858, Canberra ACT 2601.

Model status – the DSS has been fully operational for several years, though updates and improvements are made whenever inadequacies are discovered. The model is used most for estimating development times and survival of the Australian plague locust. The DSS provides a way of keeping track of, and providing forecasts for development and survival of locusts at 30-50 different sites/rainfall at one time. Most important events are signalled each week. For the spur throated locust in northern Australia, development and survival is modelled at 800 sites in northern Australia. The modelling is accurate enough that surveys are only conducted every 2-3 generations unless significant increase is forecast.

Ownership/Availability – the DSS has not been released for general use but is available in collaboration with the developers.

History of development – the DSS is the result of 15 years of R&D by various staff at the APLC. The user interface to weather data was implemented in 1997. NOAA NDVI 14-day composites from 1998, available within 1 week of sample period from 2002. Dymex models upgraded and implemented 2000.

Documentation – descriptions are given in the following references and web address *http://www.affa.gov.au/content/output.cfm?ObjectID=D2C48F86-BA1A-11A1-A2200060B0A00562*

Deveson T. & Hunter DM. 2002. The operation of a GIS based decision support system for Australian locust management. *Entomologica Sinica* 9: 1-12.

Hunter DM. & Deveson T. 2002 Forecasting and management of migratory pests in Australia. *Entomologica Sinica* 9: 13-25.

Links to other models – Nil

Objective assessment – this model is used *operationally* so must be robust and so is updated only when inadequacies are detected, new technologies become available (e.g. readily available NDVIs since 2002), or other models (such as GRASP) are developed to a stage that models parameters *markedly* better than current modelling.

B. DETAILED MODEL DESCRIPTION

Model features – components use various scripting routines: Perl, shellscripts, AML, Avenue, Dymex.

Model processes – long term average maximum and minimum temperatures are used to make forecasts; temperatures and rainfall updated daily from Bureau of Meteorology data base and are used to update forecasts weekly; 9 am and 3 pm relative long term humidities (for soil moisture model).

Minimum data sets required – FTP from BoM; daily rainfall, daily max & min temperature files and gridded data, LAPS analysis 6-hourly files in netCDF format. Current locust distribution data in AplcFieldEntry format (CSV text files).

Parameter sets –

Development/Validation data –

Development references:

Wright DE Hunter DM & Symmons PM 1988. Use of pasture growth indices to predict survival and development of the Australian plague locust. *Journal of the Australian Entomological Society* **27:** 189-192.

Hunter DM 1983. The maintenance of body temperature in adult Australian plague locusts. *Journal of the Australian Entomological Society* **22:** 135-136.

Hunter DM & Melville MD 1994. The rapid and long lasting growth of grasses following small falls of rain on stony downs in the arid interior of Australia. *Journal of Ecology* **19:** 46-51.

Rochester et al 1996. A simulation model of long distance migration of *Helicoverpa* spp moths. *Ecological Modelling* **86:** 151-156.

Deveson T. & Hunter DM. 2002. The operation of a GIS based decision support system for Australian locust management. *Entomologica Sinica* **9**: 1-12.

Hunter DM. & Deveson T. 2002 Forecasting and management of migratory pests in Australia. *Entomologica Sinica* **9**: 13-25.

Sensitivity analyses – development model timing for plague and spur-throated locusts have been validated against field observations. Model recruitment parameters have been modified to produce observed levels of population increase, but have not been verified.

Model output -

- Locust development stage and numbers.
- Soil moisture: grass greenness and locust % survival related to soil moisture
- NDVI and ground surveys used to confirm grass greenness, locust development stage and survival

Application – the DSS is a set of computerised secondary decision and information tools that co-ordinate the collection, processing and display of a range of spatial data to forecast locust population development and to assist operations. The forecasts are used to help locate population aggregations early in a breeding sequence to enable effective preventive control. The data collection components of the DSS include wireless direct transfer of locust survey data from the field, and daily internet collections of weather data. Locust distribution and age information is collected by APLC officers on regular vehicle surveys using GPS-connected palmtop computers and sent directly to a GIS server via high frequency (HF) radio modems. Locust reports from landholders and state extension staff are also incorporated into the system. The current survey data are used to estimate broad distributions and, together with location-specific weather data, to seed locust development models to identify the timing of life stages when management is possible. Information on the distribution of rainfall, temperature and wind-fields is collected automatically from the internet and integrated with habitat information and locust distributions. NOAA satellite AVHRR NDVI imagery, scaled as an index to show the current ground vegetation greenness relative to the historical range, is now available in a timeframe to enable habitat condition information to be used to direct survey to areas where locust increase is most likely.

8. PERFECT

- Productivity Erosion Runoff Functions to Evaluate Conservation Techniques

A. OVERVIEW

Purpose - PERFECT was developed for cereal growing areas of the sub-tropics of Australia. It is a paddock scale model that simulates the major effects of management (cropping system, crop sequence, tillage) and environment (climate and soil type) and to predict runoff, soil loss, soil water, drainage, crop growth and yield. PERFECT is a mechanistic model, the overall structure is physically based, but individual processes may be represented by empirical relationships.

Keywords - runoff, soil loss, soil water, drainage, crop growth, crop yield.

Key contact/s –

Agricultural Production Systems Research Unit (APSRU)
PO Box 102, Toowoomba, QLD 4350
Email: *apsru@apsru.gov.au*
Tel: (07) 4688 1394

Model status - PERFECT is fully operational.

Ownership/Availability – PERFECT is available under license from the Agricultural Production Systems Research Unit (APSRU) at *www.apsru.gov.au*

History of development - PERFECT was developed by Mark Littleboy, David Freebairn, Mark Silburn, David Woodruff, and Graeme Hammer commencing in the early 1980s. Initially, an existing model for wheat growth was integrated with a range of water balance and erosion submodels. The development of PERFECT was finalised from 1986 to 1989. During these years, PERFECT became a cropping systems model with a substantial number of new components including crop growth submodels for sunflower and sorghum, crop residue and surface cover submodels, a wider range of erosion submodels, an in-crop nutrient balance submodel, and planting and tillage decision submodels. Although PERFECT was developed for sub-tropical grain growing areas of Queensland, it has been successfully validated and applied in semi-arid areas of north Queensland and India.

Documentation – a manual is available from
http://www.apsru.gov.au/apsru/Products/Perfect.htm

M. Littleboy, D.M. Freebairn, D.M. Silburn, D.R. Woodruff and G.L. Hammer (1999) PERFECT Version 3.0 A computer simulation model of Productivity Erosion Runoff Functions to Evaluate Conservation Techniques.

A list of publications describing the development and use of PERFECT is on the above website.

Links to other models

– used for input to other models

Objective assessment –

The *strengths* of PERFECT are it is a cropping systems model that contains dynamic water balance, crop growth, soil erosion, fallow management and planting decision submodels in an integrated framework; weather data requirements are readily obtainable; soil parameters have a physical basis and can be measured or estimated; it is capable of performing long-term simulations using historical daily rainfall data; and it has been extensively validated and widely applied.

The *weaknesses* of PERFECT are it is a one-dimensional model that simulates a single point in a landscape and does not consider partial area runoff processes or lateral movement of water; all biophysical processes are simulated on a daily timestep so processes that occur at a smaller timestep (e.g. peak runoff rate) may in some circumstances be poorly predicted; it does not have a fully interactive management module to enable the user to trigger management decisions (e.g. planting, fertiliser, irrigation and tillage) from a range of biophysical criteria; and the residue decay algorithm is non-dynamic.

9. RAINMAN
– rainfall information for better management

A. OVERVIEW

Purpose/Objective – the Rainman StreamFlow software (Clewett *et al*. 2003) is a comprehensive analysis and education package for producers, business people, educators, researchers and consultants to assess climatic risks and opportunities. The data-base of historical rainfall (3700 locations in Australia and 12,000 world-wide) can be assessed with the characteristics of daily, monthly, seasonal and annual rainfall displayed as tables, graphs and maps. The reliability and accuracy of seasonal forecasts regards the amount, timing and frequency of rainfall can be assessed in relation to SOI values or sea surface temperatures, and over any length of season. This includes statistical tests on the accuracy of forecasts and analyses of: chance of rainfall, deciles of rainfall, historical records, and historical moving averages. Drought analysis lists moderate (driest 10% of years) and severe (driest 5%), and their length. Climate analysis shows monthly relative humidity, temperature (max, min, frost) and evaporation for a subset of 625 stations. The package was previously known as Australian Rainman and is now distributed in Standard, Educational and Professional editions as Rainman Streamflow containing a further data set of historical and modelled streamflow (400 locations in Australia) data. Data can be imported and monthly rain can be updated from the internet. Educational materials on the CD include an electronic copy of the book 'Will It Rain', tutorials on managing climatic risk, map and graphics libraries, and a set of scientific papers about Rainman and seasonal forecast applications.

Keywords – rainfall, climate, variability, El Nino, SOI, drought, streamflow

Key contact/s –

Dr Jeff Clewett or Mr Ian Partridge
Department of Primary Industries
PO Box 102
Toowoomba QLD 4350
Australia
Email: *qcca@dpi.qld.gov.au*
Tel: (07) 4688 1200
Fax: (07) 4688 1477

Model status – the package is fully operational, tested and validated with 7500 copies distributed.

Ownership/Availability – Rainman is published by the Department of Primary Industries & Fisheries Queensland and was developed with several organisations including the Dept of Natural Resources Mines and Energy, Commonwealth Bureau of Meteorology, ICE Media, West Australia Dept of Agriculture, NSW Agriculture, Rural Industries Research and Development Corporation, Land and Water Australia, Australian Centre for International Agricultural Research, University of Melbourne and the Meat Research Corporation. Rainman is available in Standard ($125), Educational ($125) and Professional ($450) editions through outlets in all states and from the Client Service Centre, Department of Primary Industries and Fisheries, PO Box 102, Toowoomba QLD 4350. A corporate site licence is available.

History of development –

Version 1 of Rainman was launched in October 1991 with data and analyses relevant to Queensland and '*Will It Rain?*' as a companion book. Australian Rainman Version 2, was released in October 1994 with monthly rainfall for 3,700 locations Australia wide and a revised version of *'Will it Rain?*'. Australian Rainman Version 3 was released in June 1999 as a Windows package and included: long-term daily rainfall for all locations; several new seasonal forecast analyses; new daily rainfall analyses; an electronic version of 'Will it Rain?' with animations describing ENSO and its impact on Australia; some 7,000 maps from the Long Paddock website; a suite of tutorials about climate risk in agriculture; a graphics library; scientific papers and references; as well as case studies of how farmers and business people are using climate information in their management. The current version of Rainman (Rainman StreamFlow Version 4.3) was released in October 2003 as a major upgrade to the software. This expanded the tutorials and help information, improved the rigour of testing seasonal forecasts, upgraded the SST based forecast system and enabled mapping of seasonal forecast and drought analyses. It also incorporated new data sets for international rainfall (9500 locations) and Australian streamflow (400 locations) and enabled the import of temperature and modelled pasture growth data for analyses.

Documentation –

Rainman StreamFlow (Clewett *et al.* 2003) is fully documented and includes tutorials. Ten scientific papers on the Rainman CD describe data, analyses and applications. The scientific citation for Rainman is:

Clewett, J.F., Clarkson N.M., George, D.A., Ooi, S.H., Owens, D.T., Partridge, I.J. and Simpson, G.B. (2003). Rainman StreamFlow version 4.3: a comprehensive climate and streamflow analysis package on CD to assess seasonal forecasts and manage climate risk. QI03040, Department of Primary Industries, Queensland.

Links to other models – output from Rainman can be saved to file and used in other applications.

Objective assessment –

Rainman is a very easy to use package for analysing rainfall information. It can be of great benefit to those involved in primary production, agribusiness and policy making, and to students interested in developing their knowledge of climate and seasonal forecasting.

Strengths

- Rainman helps introduce an awareness of climatic variability and has an educational value through its tutorials etc.
- it allows evaluation of climatic risk, trends in rainfall over the long-term, frequencies and timing of rainfall, and identification of seasonal breaks
- seasonal forecasts can be targeted and thus made relevant to the information and decision making needs of users
- it provides clear information to both novice and advanced users concerning the reliability and accuracy of seasonal forecasts for both specific locations and groups of locations.

Weaknesses

- it is now a comprehensive package and so takes some time for a new user to find their way around the menus within the package and to familiarise themselves with everything that is in the package.
- Internet updating of monthly rainfall is possible but internet updating of daily rainfall and streamflow data is not possible.
- not able to assess seasonal forecast methods other than the average SOI, SOI Phases and SST Phases.

- while results can be exported to file or cut and pasted into a spreadsheet, there are limited options for saving analysis results in a user friendly form

10. SedNet
– Sediment and Nutrient Budgets for River Networks

A. OVERVIEW

Purpose - SedNet constructs sediment and nutrient budgets for river networks to identify patterns in the material fluxes. These budgets are an account of the major sources, stores and fluxes of material. The framework for constructing the budgets is a river network, consisting of a series of links that each extend between stream junctions. Sediment and nutrient budgets are computed for each link using conceptual representations of erosion, delivery, transport, transformation and deposition processes. Export from the catchment takes all these factors into account. SedNet includes data on measurements of river discharge, and geographical mapping of soils, vegetation cover, geology, terrain and climate.

Keywords - sediment, suspended, bedload, hydrology, erosion, transport, delivery, runoff, nutrients

Key contact/s

Dr Scott Wilkinson
CSIRO Land and Water
GPO Box 1666, Canberra ACT 2601
Email: *scott.wilkinson@csiro.au*
Tel: (02) 6246 5774

Dr Jon Olley,
CSIRO Land and Water
GPO Box 1666, Canberra ACT 2601
Email: *jon.olley@csiro.au*
Tel: (02) 6246 5826

Model status - SedNet is fully operational but is in continual development (including model evaluation and quality control checks) at CSIRO Land and Water and the CRC for Catchment Hydrology to improve performance.

Two versions have been developed; an Arcinfo version used as a research tool by CSIRO Land and Water that is capable of predicting both sediments and nutrients, and Windows-based version written in TIME (The Invisible Modelling Environment) that available for general use. The latter model currently deals with erosion rates and sediment, and from Version 2.0 onwards with nutrient fluxes***.***

Ownership/Availability - IP is owned by CSIRO Land and Water. The Windows-based version is available free under licence.

History of development - SedNet was developed by CSIRO Land and Water (Ian Prosser, Chris Moran, Jon Olley, Bill Young) from the late 1990s and used and tested widely in the NLWRA.

Documentation

Prosser, I., Rustomji, P., Young, B., Moran, C. and Hughes, A. (2001) Constructing river basin sediment budgets for the National Land and Water Resources Audit. *CSIRO Land and Water Technical Report 15/01*.

Wilkinson, S., Henderson, A., and Chen, Y. (2004) *SedNet User Guide*, Version 1.0. Client Report for the Cooperative Research Centre for Catchment Hydrology; CSIRO Land and Water; Canberra. (*www.toolkit.net.au/sednet)*

Anon. (2002) Managing regional water quality. Brochure, CSIRO Land and Water, Canberra: *http://www.clw.csiro.au/publications/general2002/managing_regional_water_quality.pdf* ; 4 pp.

Links to other models - output from SedNet has been compared with results of EMSS modelling in south east Qld. The models produced different patterns of contaminant supply and SedNet was recognised as providing greater predictive capacity and a more accurate representation of the spatial patterns.

Objective assessment - SedNet produces long-term budgets accounting for all major sources and sinks of sediments with a focus on Australian systems. The focus on the processes of generation, transport and deposition make the model particularly useful for targetting actions to reduce erosion and nutrient supply. It has been tested widely through the NLWRA and numerous regional studies against observed levels of suspended sediments and sediment tracing data.

SedNet produces long-term averages of sediment and nutrient loads, although results can be disaggregated to provide the temporal patterns of delivery. Careful data preparation is required in order to predict present-day erosion patterns accurately. While SedNet provides a very suitable modelling framework for rangeland assessment, it has not been applied and tested broadly in rangeland landscapes. It is likely that the process representations of erosion, transport and deposition will require development to perform well in this environment. There will also be significant data preparation (streamflow, surface and channel erosion, etc) required to apply the model in these regions.

11. SHEEPO

– a model for pasture and grazing management in temperate climates

A. OVERVIEW

Purpose/Objective - SheepO is intended to assist graziers in temperate climates assess grazing management and pasture management options. It is intended to be a model of intermediate complexity, avoiding the high level of parameterisation of more generic environmental models which have greater process detail, particularly soil-plant processes. It has been applied in the winter rainfall areas of Australia, Brazil and the Falkland Islands (version 3) and more recently in areas which have a higher component of summer rainfall (version 4).

Keywords - sheep, pasture growth, liveweight gain, temperate grasslands, stocking rate

Key contact

Malcolm McPhee
Elizabeth Macarthur Institute
NSW Agriculture
Menangle, 2570, NSW, Australia.

Model status - Version 4 is operational with ongoing development by the author.

Ownership/Availability - the model is available for $200 for a single copy plus manual ($300 for six copies and one manual).

History of development - the initial development of SheepO dates back to the early 1980's (White, D.H. *et al*. (1983). A simulation model of a breeding ewe flock. *Agricultural Systems*, 10: 149-189). It has continued to evolve with SheepO version 3 released in 1992. Version 4 was released in 1996 after improvements in the routines for pasture growth and sheep production including three 'regional' models of water balance, shoot death and digestibility of green pasture.

Documentation

McPhee MJ (1996) SheepO version 4.0: A sheep management package E*nviron Software* 11: 105-112.

McPhee MJ, Ayres JF (2000) Application of the decision support system SheepO for predicting pasture and sheep production on temperate perennial pastures. *Asian-Australian Journal Animal Sciences* 13: 149-149 Suppl. S JUL

Ayres JF, McPhee MJ, Turner AD, et al. (1999) The grazing value of tall fescue (Festuca arundinacea) and phalaris (Phalaris aquatica) for sheep production in the northern tablelands of New South Wales, *Australian Journal of Agricultural Research* 51: 57-68.

McPhee MJ, Ayres JF, Curll ML (1997) Growth periodicity of introduced pastures on the northern tablelands of New South Wales, *Australian Journal of Agricultural Research* 48: 831-841.

Links to other models - None

Objective assessment

SheepO is a model constructed to deal with sheep grazing systems in the higher rainfall, temperate zones. These zones arguably do not fit the usual definition of rangelands in terms of the climate, soil and vegetation resources nor the production and natural resource management issues. Consequently, many of the elements of more standard rangelands models are not incorporated into SheepO such as growth/competition of trees and shrubs, soil erosion and fire. Similarly, it is unclear how the pastures simulated in the model will respond to extreme water stress. In validation studies (e.g. McPhee 1996), SheepO performed reasonably well for total and green pasture biomass (although not when green pasture was low in autumn) and for liveweights at low stocking rates but poorly for liveweights at high stocking rates. Very substantial effort would be needed to make the model more relevant and robust for most rangelands in Australia.

12. SLIM
– Strategic Landscape Investment Model

A. OVERVIEW

Purpose/Objective – SLIM was developed for the NSW to help determine: (1) the change in natural resource condition (erosion, sediments, nutrients, salts and water yield) over time following some type of landscape treatment; (2) the likely cost required to affect the landuse change, and thereby create desired changes in resource condition, on privately owned freehold or leasehold land; (3) the level of environmental benefit associated with that change, measured using weighted time-discounted indices and, where marginal cost functions exist, dollars; and (4) the optimal allocation of funds from a program budget to alternative locations or regions for different landscape treatment options.

Keywords – landuse, environment, natural resources, optimal funding, erosion, sediment

Key contact –
Stefan Hajkowicz
CSIRO Sustainable ecosystems
306 Carmody Road, St Lucia Qld 4067
Email: *stefan.hajkowicz@csiro.au*
Tel: (07) 3214 2327

Model status – SLIM is available in prototype form only. Further testing and refinement is required before it could be used in real applications

Ownership/Availability – the model is jointly owned by CSIRO and the NSW Department of Natural Resources

History of development – developed for NSW; prototype completed in 2003.

Documentation – a publication is in draft however, a description of the project and much of the model is provided in the final report:

Hajkowicz, S., Perraud, J., De-Rose, R., Austin, J. and Dawes, W. (2003) *The Strategic Landscape Investment Model*: A final report to the NSW Department of Sustainable Natural Resources. 68pp.

Links to other models – SLIM uses linkages to the Biophysical Capacity to Change model (BC2C), a land use change model, to the soil erosion model SedNet, to the nutrient flow model (Annex) and to the NSW Carbon Sequestration Predictor.

Objective assessment –
SLIM uses local environmental conditions such as slope steepness, soil type, rainfall, and underlying geology to determine the landscape response of resource condition attributes such as: soil erosion rate; sediment concentration; nitrogen and phosphorus runoff; salt loadings; water yield; and carbon sequestered. It combines weighted attribute indices of environmental benefit with cost functions for water salinity and sedimentation to determine economic benefit. The model runs on a state wide basis using 1.1km^2 grid cells. The model can be run over long time periods, say, 50 or 100 years.

The strength of SLIM are in its integration of land use, land response and environmental benefit from land use change. SLIM is currently the only model which allows optimisation of land use change and target areas to get maximum benefit from resource funding.

The weakness in SLIM is the limited data available for the initial parameterisation of the models. There is only limited data available on carbon sequestration and the effects of land use change on salt loads etc.

13. SWAT

- Soil and Water Assessment Tool

A. OVERVIEW

Purpose/Objective - SWAT is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. It predicts the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large river basins. Swat includes the following components and processes – weather, surface runoff, percolation, evapotranspriation, transmission losses, pond and reservoir storage, crop growth, irrigation, groundwater flow, nutrient and pesticide loading, and water transfer. SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modelled by SWAT using this input data.

Keywords - runoff, nutrients, pesticides, land management, sediment movement

Key contact/s

Jeff Arnold	Hydraulic Engineer	ARS-Temple	jgarnold@spa.ars.usda.gov
Nancy Sammons	Computer Specialist	ARS-Temple	nsammons@spa.ars.usda.gov
Raghavan Srinivasan	Agricultural Engineer	TAES-Temple	r-srinivasan@tamu.edu
Mauro DiLuzio	Research Associate	TAES-Temple	diluzio@brc.tamus.edu

Model status - SWAT is fully operational.

Ownership/Availability - SWAT is a public domain model actively supported by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA.

History of development - SWAT was developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was created in the early 1990s based significant contributions from several models - SWRRB (Simulator for Water Resources in Rural Basins), CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems), and EPIC (Erosion-Productivity Impact Calculator). Since then it has undergone continued review, expansion of capabilities, development of interfaces, extensive validation. SWAT has been used in Australia for a number of applications.

Documentation - documentation, including the SWAT2000 User's Manual, is available at *www.brc.tamus.edu/swat/*. There are numerous publications listed on the website describing the development and use of SWAT including:

Arnold, J.G., R. Srinivasin, R.S. Muttiah, and J. R. Williams. (1998) Large Area Hydrologic Modeling and Assessment: Part I. Model Development. *JAWRA* **34,** 73-89.

Arnold, J.G. and Allen P.M. (1992) A Comprehensive surface-groundwater flow model. *J. Hydrology* **142**, 47-69.

Arnold, J.G., Williams, J.R., and Maidment D.A. (1992) Continuous-Time Water and Sediment-Routing Model for Large Basins. *Journal of Hydraulic Engineering* **121**, 171-183.

Srinivasan, R. and J.G. Arnold. (1994) Integration of a Basin-Scale Water Quality Model with GIS. *Water Resources Bulletin* **30**, 453-462.

Srinivasan, R., J.G. Arnold, R.S. Muttiah, and P.T. Dyke. (1995) Plant and Hydrologic Simulation for the Conterminous U.S. Using SWAT and GIS. *Hyd Sci &Tech* **11,** 160-168.

Links to other models - SWAT accepts output from EPIC.

Objective assessment - SWAT uses readily available inputs; the minimum data required are commonly available. Catchments with no monitoring data (e.g. stream gauge data) can be modelled. SWAT is computationally efficient. Simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money. SWAT enables users to study long-term impacts. Users can initially be overwhelmed by the variety and number of inputs used.

14. SWIM

- Soil Water Infiltration and Movement - a software package developed within CSIRO Land and Water for simulating water infiltration, evapotranspiration, and redistribution.

A. OVERVIEW

Purpose/Objective - the overall purpose of the model is to address issues relating to the soil water and solute balance. As such it is a research tool that can be integrated in laboratory and field studies concerned with soil water and solute transport. It is also eminently suitable for management and education. SWIM can deal with:

- layered and gradational soils such as occur in field soils where hydraulic properties vary with depth down the profile, either abruptly or gradually,
- saturated/unsaturated conditions as can occur at layer interfaces, which result in locally perched water,
- surface ponding as can occur under high rainfall intensities,
- surface runoff, where 'excess' water can be removed from the system,
- surface sealing, where the properties of the surface may vary directly as a function of rainfall energy, and hence as a function of time,
- rainfall dynamics, so that real storm intensities (down to 1-minute resolution and below) can be simulated,
- solute transport,
- flexible description of hydraulic properties and boundary conditions
- vapour flow, hysteresis, bypass flow, osmotic effects, and potential subsurface downslope flow,
- specifications of root length density with depth and time, and potential plant water uptake with time,
- allows for 'cultivations' or 'disturbances' of the soil surface which enable the application of dry fertiliser (solute) and resetting of the surface conductance and surface roughness values at specified times.

Keywords – soil water, infiltration, evaporation, redistribution, solute transport, Richards equation

Key contact/s –

Keith Bristow
CSIRO Land & Water
University Drive, Townsville, Qld, 4810
Email: *Keith.Bristow@csiro.au*
Tel: (07) 4753 8596

Model status - the model is fully operational. It is supported by CSIRO Land and Water.

Ownership/Availability - SWIM is available from CSIRO Land and Water. It is generally used as a research model.

History of development - the first version (SWIMv1) was published in 1990 (Ross, 1990b). Version 2 of the model (identified as SWIMv2.0), which combines water movement with transient solute transport and which accommodates a variety of soil property descriptions and more flexible boundary conditions, was completed in 1992.

SWIM v2.0 is based on a numerical solution of the Richards' equation and the advection-dispersion equation. It can be used to simulate runoff, infiltration, redistribution, solute transport and redistribution of solutes, plant uptake and transpiration, soil evaporation, deep drainage and leaching. Soil water and solute transport properties, initial conditions, and time dependent boundary conditions (e.g., precipitation, evaporative demand, solute input) need to be supplied by the user in order to run the model.

Documentation

CSIRO Land and Water have an entry point on their website for SWIM (*http://www.clw.csiro.au/products/swim/index.html*).

Key publications which deal with testing and description of the model include:

Verburg, K., and W.J. Bond. (2003) Use of APSIM to simulate water balances of dryland farming systems in south eastern Australia. *CSIRO Land and Water Technical Report 50/03*, 62 pp. *http://www.clw.csiro.au/publications/technical2003/*

Verburg, K., P.J. Ross, and K.L. Bristow (1996) SWIMv2.1 *User manual*. CSIRO Division of Soils Divisional Report 130, 107 pp.

Verburg, K. (Ed.) (1996) Methodology in soil water and solute balance modelling: An evaluation of the APSIM-SoilWat and SWIMv2 models. Report of an APSRU / CSIRO Division of Soils workshop held in Brisbane, Australia, 16-18 May 1995. *CSIRO Division of Soils Divisional Report 131*, 88 pp.

Links to other models

SWIM has been implemented as a module in the APSIM modelling framework (Keating, B.A., *et al*. 2003. An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* 18, 267-288.) where it can be linked to other APSIM modules or tested against them whilst keeping all other components constant. SWIM has been tested against the APSIM module SoilWat (Verburg 1996).

Objective assessment

SWIM is not structured as a rangeland model. It doesn't have the pasture dynamics, tree/shrub dynamics, management options or livestock production/interaction components that characterise rangeland models. It has mostly been applied in cropping systems or in analyses of systems such as effluent application where understanding of the movement of solutes in the soil profile is critical. It has been implemented in APSIM, but the limitations of APSIM in relation to rangeland simulation (see section on APSIM) apply consequently to that implementation of SWIM too. Furthermore, SWIM appears to be quite sensitive to variation in some of the key soil parameters it uses and this may be an issue in the data poor and highly variable rangelands.

Miscellaneous models – other models encountered during the project but not formally reviewed or included in model synthesis

Wind erosion models

We are unaware of any generalised models for simulating wind erosion however, there has been some work done deriving empirical relationships based on historical incidence of dust storms (McTainsch *et al.* 1990). The relationship uses annual values of wind, rain and evaporation to determine an erosion value. There are several limitations to the relationship:

- it is based on recorded dust storms in a region but the storm could have arisen elsewhere;
- it is based on <u>annual</u> values of rain, wind and evaporation;
- it doesn't take into account the <u>soil erodibility</u>;
- it doesn't take into account <u>land use</u>.

McTainsch, G.H, Lynch, A.W. and Burgess, R.C. (1990) *Australian Journal of Soil Research* **28**, 323-339.

Vertebrate pest models

While there are numerous publications describing some form of modelling of populations of vertebrate pests e.g. foxes and rabbits (Pech and Hood 1998), house mice (Pech *et al*. 1999, Kenney *et al*. 2003), feral pigs (Choquenot 1998) and donkeys (Choquenot 1990), there appears to be no generalised model for any particular species. Generally, these models are based on empirical relationships (Pech and Hood 1998, Choquenot 1998) or multiple regressions (Kenney *et al*. 2003), are highly localised (Pech *et al*. 1999) or discuss predator-prey relationships in theoretical terms (Sinclair *et al*. 1998). Potential climatic regions suitable for any particular species can be modelled using the CLIMEX model (see description this document) provided the necessary relationships and parameters are known. Similarly, empirical population models can be built using modelling software such as DYMEX (see description below).

Choquenot, D. (1998) Testing the relative influence of intrinsic and extrinsic variation in food availability on feral pig populations in Australian rangelands. *Journal of Animal Ecology*, 67: 887-907.

Choquenot, D. (1990) *Journal of Mammology*, 71: 151-155.

Kenney, A.J., Krebs, C.J., Davis, S., Pech, R. and Singleton, G.R. (2003) Predicting house mice outbreaks in the wheat growing areas of southeastern Australia. In Rats, Mice and People: Rodent Biology and Management, (eds. G.R. Singleton, L.A. Hinds, C.J. Krebs and D.M. Spratt), Australian Centre for International Agricultural Research, Canberra, pp. 325-328.

Pech, R.P. and Hood, G.M. (1998) Foxes, rabbits, alternative prey and rabbit calicivirus disease: ecological consequences of a new biological control agent for an outbreaking species in Australia. *Journal of Applied Ecology* 35:434-453.

Pech, R.P., Hood, G.M., Singleton, G.R., Salmon, E., Forrester, R.I. and Brown, P.R. (1999) Models for predicting plagues of house mouse (*Mus domesticus*) in Australia. In Ecologically-based management of rodent pests, (eds. G. Singleton, L. Hinds, H. Leirs and Z. Zhang), Australian Centre for International Agricultural Research, Canberra, pp. 81-112.

Sinclair, A.R.E., Pech, R.P., Dickman, C.R., Hik, D., Mahon, P. and A. Newsome, A.E. (1998) Predicting the effects of predation and the conservation of endangered prey. *Conservation Biology* 12:564-575.

INSIGHT – integrated systems modelling for catchment management

The INSIGHT model is been developed to use as a learning tool for resource mangers across the full range of social, economic and environmental issues of a catchment. It is a spatially explicit model, combining agricultural production point models with spatial hydrological models. The model runs on a 20-year time span. Particular issues addressed are native vegetation degradation, biodiversity decline, soil acidification, salinity, catchment water balance, farm profitability and rural population adjustment. The model is built in a modular form so that additional modules can be added as desired. INSIGHT does not make predictions of future conditions or give accurate quantification of the impacts of policy changes. Rather, it facilitates joint learning by policy makers, stakeholders and modelers. The program has been developed for the Lachlan catchment but could be applied to other regions. However, this would require collection of considerable scoping of issues, information on key indicators and system behaviour, and options. For more information see:

http://www.lwa.gov.au/downloads/final_reports/CWE18.pdf

Key contact: Roger Gorddard, CSIRO Sustainable Ecosystems, GPO Box 284, Canberra, ACT 2601. Email: roger.gorddard@csiro.au; Tel: (02) 6242 1789.

WAVES – An integrated energy and water balance model

WAVES is a one-dimensional daily-timestep model that simulates the fluxes of mass and energy between the atmosphere, vegetation, and soil systems, which has been under development since 1993. It is a process-based model that couples these systems by modelling the interactions and feedbacks between them. WAVES attempts to model each sub-system with a consistent level of detail, so that no area is over emphasized or requires too many parameters, and similarly no area is treated in a trivial manner. More than this, WAVES tries to strike a balance between the complexity of the model as a whole, the usefulness of the model and its ease of use, and the accuracy of the model outputs.

The model processes include: interception of rainfall and light by canopy; surface energy balance; carbon balance and plant growth; soil evaporation and canopy evapotranspiration; surface run-off and infiltration; soil moisture dynamics; drainage/recharge; solute transport of salt; and watertable interactions. The minimum dataset requirements are daily maximum and minimum temperatures and daily rainfall. There are a considerable number of parameters required for soil and vegetation components of the model. For the soil, these are the relationship between soil water potential, volumetric water content and hydraulic conductivity. There are some 22 vegetation parameters, however most of these can be measured directly or taken from plant physiology literature. The strengths of WAVES are: (1) it is a generic model not specifically designed for any particular soil type, vegetation system or climatic region; (2) it represents a wide range of dynamic processes with a consistent level of complexity; (3) weather data is readily available; (4) soil water characteristics are readily measured or easily estimated; (5) it can be run over a long period; and (6) it has been extensively tested in several countries. Its weaknesses are: (1) it is a one-dimensional model; (2) not all soil properties are modeled e.g. cracking soils; (3) it runs on a daily time-step and hence ignores phenomena which occur at shorter time intervals e.g. rainfall intensity; (4) the plant growth models only the plant growth in relation to water and not phenology; (5) it does perform any nutrient cycling or leaching.

The WAVES model software and documentation is available, free of charge, from the web, or through collaboration or direct application to CSIRO Land and Water, GPO Box 1666, Canberra ACT 2601. Ph: (02) 6246 5700. Web site:
http://www.clw.csiro.au/products/waves/index.html

DYMEX – population model development software

DYMEX provides researchers with a means of building complex population models for any species simply by clicking on menu options and answering questions. No programming and therefore no code debugging is needed to build a model. Simple models can be constructed relatively easily with limited time spent on learning DYMEX. A good understanding of the biology of the organism is still needed but DYMEX takes the pain out of model building by automating many processes.

The models created can be used for real-time decision support or to explore the impact of a wide range of conditions, including various control strategies. Software support is provided by CSIRO Entomology, email *DYMEX@csiro.au*

The software is available for purchase from CSIRO Publishing, PO Box 1139, Collingwood, Victoria 3066 (email: *sales@publish.csiro.au*). Demo versions can be downloaded from the web: http://www.ento.csiro.au/research/pestmgmt/IPMModellingNetwork/software2.htm\

ICMS – integrated systems model development software

ICMS has been designed for people who aren't professional programmers or modellers but have some modelling knowledge and can write some code. It allows such people to write new and/or import existing models (written in ICMS and distributed in ICMS model libraries) that can be linked to build up an integrated representation of a system (e.g. a river basin) containing linked suites of modelled processes. It is particularly suited to scenario exploration – i.e. exploring and comparing the impacts of different settings of input conditions (e.g. distribution of land use, or daily rainfall patterns) on key output indicators. The software is available under licence from CSIRO Land and Water. See web sites:

http://www.cbr.clw.csiro.au/icms/News/icmsnamenews.html
and http://icam.anu.edu.au/html/icms.html

Rainfall Reliability Wizard

This package is owned by the Bureau of Rural Sciences and is described on their websire thus:

"The Rainfall reliability Wizard is used for broad scale analysis of rainfall across Australia. The Wizard uses 25x25km grids of total monthly rainfall, Australia wide, from the Commonwealth Bureau of Meteorology. This is a 'first-stage' analysis tool used both to rapidly evaluate rainfall events and also to characterise rainfall risk across broad geographic areas. For example, the Wizard may be used to determine rainfall amount for an Autumn season, and then used to calculate the percentile ranking for that season against the historical record (100 years). Conversely, in terms of risk, the reliability of receiving a defined rainfall amount either for a season (inter-seasonal) or for individual months in a season (intra-seasonal) are easily calculated. Importantly, all of these analyses can be quickly imported into commercial GIS packages."

RRW is available from the Bureau of Rural Sciences, GPO Box 858, Canberra ACT 2601. Contact the Climate and Agricultural Risk (CAR) group at BRS. Email: *car@brs.gov.au*

Web site: *http://www.affa.gov.au/content/output.cfm?ObjectID=D2C48F86-BA1A-11A1-A2200060B0A06289*

5. Synthesis of models

This review has highlighted the diversity of models that have been applied in the rangelands to address issues associated with natural resource management. These models range from purely biophysical to socio-economic and cover spatial scales from small plots or quadrats, to patch, paddock, landscape, enterprise, catchment, region or national scale (Table 2). The uses of these models vary from research to management to policy.

It appears the complexity and wider applicability of these models has been dependent on their intended use at the time of development. Models originally developed for research and designed to provide insights into the dynamics of a particular part of a system tend to be more complex, bioregionally or biome specific and more data and parameter intensive than most of the models developed for management or policy application.

There are three main limitations to the wider application of many models:

1. Little understanding or knowledge of the model beyond the central architect. Unless the model is well documented and there is widespread use and uptake by a range of users it is unlikely the model will persist in the longer term. Eventually the model "champion" moves on to new areas of work and without a wider "user" group to maintain momentum the model disappears from use.
2. The model has been developed for a very specific application or environment. A number of research models have been developed to better understand system dynamics associated with a field experiment and to provide insights into key gaps in understanding of that particular system. As a result they have limited utility beyond their original intended use and tend to have a limited life span.

The models in Category 3 tend to fall into these first two groups. Category 3 models tend to be dominated by research models, which may have served their purpose. Even though these models are no longer being actively used, key processes or insights may be captured in newer research models or broader scale management models.

3. The model is widely applicable and has potential for on-going use but limitations in data or challenges in parameter estimation prevent wider use. It is these models (Category 1 or 2 for rangeland specific models or Category 4 for broader models that can or have been applied in the rangelands), where effort should be focussed on synthesising data sets to improve their use.

Summary of data requirements of the models

Table 2 contains a consolidated list of data inputs required by the various models reviewed in this project. These data and information requirements can be summarised into four groups of models: ecological/pasture/hydrological models operating at either (a) small or (b) large spatial scales; (c) economic models and; (d) population models of wildlife or pests. The data and information requirements are described below in more detail.

(a) Ecological/pasture/hydrological models operating at relatively small spatial scales

Most of these models are mechanistic or process based and most commenced life as research models and as such have significant requirements in terms of data and parameters and in a number of models it is the absence of more comprehensive data libraries that is limiting wider application. The data needs fall into three general groups:

- Climate - at least rainfall is required (daily or monthly basis), but more often than not other inputs such as temperature, evaporation, wind and solar radiation are required.

- Soils – most ecological/pasture models require some data on water holding capacity for either single or multiple layers and for more hydrological models there are data requirements on soil physical characteristics
- Vegetation – some broad data is usually required on vegetation in terms of tree/shrub layer and the herbaceous layer

(b) Ecological/pasture/hydrological/carbon models operating at broad spatial scales (sub-catchment, regional or national)

Models operating at this scale tend to be much more oriented towards management or policy and on the whole tend not to be process oriented and have simpler data needs and little user input in parameter estimation. Most still require some data inputs in terms of climate, soils and vegetation but these datasets are more widely available.

(c) Economic models

Most economic models developed for the rangelands have focussed on pastoral enterprises and the majority have links to natural resource management through climate and or pasture. These models have a management focus and vary from fairly static models of enterprises to those that mimic herd dynamics and interact with climate and/or pasture in a fairly complex way. These models are designed for assessing different management scenarios and are therefore intended for use with land managers. However, they can be complex to use, especially where there are links to climate and pasture growth. Most economic models require inputs on property structure, size, costs and prices though the ABARE model operates at the Shire scale and relies on Australian Bureau of Statistics datasets rather than user input at the enterprise level.

(d) Population models of wildlife and pests

There are relatively few models of wildlife or pests in the rangelands. Most of the models have fairly “hard-wired” animal population dynamics and the required data sets are usually only rainfall, harvest rate, and some indicator of habitat condition e.g. NDVI or pasture growth out of a model like GRASP.

6. Addressing data needs and gaps

(i) Climate data

A large number of models require climate data at daily or monthly time-steps. Nearly all of the models requiring climate inputs need rainfall and a number also require other agro-meteorological variables such as temperature, evaporation, radiation, wind. Climate datasets are widely available through the SILO website (http://www.bom.gov.au/silo/) and data available through SILO meet nearly all model requirements as historical daily climate data can be provided for anywhere in Australia as patched point data or gridded data sets. Monthly data is also available through SILO and other packages such as RAINMAN.

(ii) Soils data

A data limitation for many vegetation dynamics, pasture and animal models is good data on soil characteristics relating to plant growth. The requirements are usually for soil depth and soil water holding capacity either for the full soil profile or for different soil layers. Some of the hydrological models require additional soil physical and chemical characteristics. These soil datasets are not available in a synthesised way as most have been built up over time from widely disparate field studies. Many natural resource models in the rangelands could benefit from having a much better soils library of key soils attributes based on soils data collected from the field. Clearly these datasets will still only spatially cover a fraction of the land types and regions where modelling is required. These field data sets could be supplemented with compiled tables estimating typical ranges for soil properties associated with each principal profile form (PPF) of the Factual Key of Australian Soils that have been linked to the Atlas of Australian Soils, to provide estimates of specific soil properties for each map-unit (see Mckenzie et al. 2000 for methodology). Using this methodology soil properties have been estimated using a simple two-layer model of the soil consisting of an A and B horizon that has led to estimates of horizon thickness, texture, clay content, bulk density, grade of pedality and saturated hydraulic conductivity. The estimates of thickness, texture, bulk density and pedality have been used to calculate the available water capacity for each layer, a critical dataset for most of the models that estimate plant growth or length of the growing season.

(iii) Vegetation data

Many of the ecological and soils/hydrology models need estimates of vegetation cover and/or structure e.g. information on the tree and herbaceous basal area, functional group composition etc. As with the soils data it would be useful to have a synthesised data library of vegetation attributes that are most useful to natural resource models. For a number of models data needs could be filled by the National Vegetation Information System. The NVIS vegetation classification system contains information on vegetation structure (growth form, height and cover) and floristics (genus and species). The NVIS information hierarchy summarises detailed vegetation association data at six levels of description. Level 1 (Class) is the most general description describing a single vegetation type (e.g. tree, tussock grass etc.) while Level 6 (Sub-association) is the most complex, describing up to 5 vegetation strata/layers, 5 growth forms and 5 species per layer.

The six strata are:
- Class (L1)
- Structural Formation (L2)
- Broad Floristic Formation (L3)
- Sub-Formation (L4)

- Association (L5)
- Sub-Association (L6)

(iv) Economic data

Current rangeland models that contain an economic assessment linked to the biophysical system through production and/or climate rely on data inputs at the enterprise scale or the regional scale. Most enterprise scale models require quite detailed information on property size, herd structure, infrastructure etc and this has to be done on a case by case basis and often involves confidential data which creates issues for making data more widely available.

Current regional scale models rely on statistical data sourced through the Australian Bureau of Statistics and ABARE's farm survey data, which is not publicly available. Economic models would benefit from having ABS and ABARE data that is available in a more accessible form for model use.

Table 2. Synthesis of natural resource models in the rangelands

Model Name	Model type	Spatial Scale	How widely is the model used?	Ease of use in terms of parameter and data requirements	Key issues in ease of use or wider application	Key inputs	Key outputs
AussieGrass	Pasture	National point based	Maintained by single institution (QDNRME)	Difficult	Availability of key data at national scale	Rainfall, temperature, radiation, evaporation, stock numbers	Growth, TSDM, cover, run-off, LWG, wool growth, soil water
Breedcow/ Dynama	Animal/economic	Property	Widespread	Relatively easy	Limited to herd and financial management	Branding and death rates, cost & prices, assets & liabilities	Herd structure, profitability, financial projections, cash flow
Century	Soil carbon/nitrogen	National point based	Widespread	Difficult	Obtaining necessary parameter data	Rainfall, temperature, soil characteristics, nitrogen	Soil carbon & nitrogen, forest biomass, CO2 fluxes, plant biomass, plant nitrogen
Flames	Tree/ Pasture/Fire	Landscape cell	Currently limited	Difficult	Obtaining necessary parameter data	Rainfall, temperature, humidity, wind speed, land type, fire frequency	Tree dynamics, carbon, soil water, GH gas emissions
GRASP	Pasture/Animal/Soil Loss	Point	Widespread	Moderately difficult	Soil water properties, grass and tree basal area, good animal module	Climate, soil data, tree and grass characteristics, stocking rate/ utilisation	Pasture yield, utilisation, liveweight gain, soil loss
Growest Plus	Pasture/climate	National grid based	Currently limited	Easy	Obtaining climate data on a national grid	Rainfall, temperature, radiation, evaporation	Climate & growth indices
HerdEcon	Economic/animal	Property	Widespread	Moderately difficult	Good on-property data relating to reproduction and mortality rates, animal classes and basic financial record keeping	Property structure, prices	Herd numbers, cash flow
BB-SAFe	Economic/animal	Property	Limited	Easy	More detailed simulations can be performed by RANGEPACK Herd-Econ	Area, costs, number of stock	Cost of different tactics and scenarios
agFIRM	Economic/animal	Property	Not Released	Very restricted access to required data	Data required is property of ABARE and not for general release	ABARE Pasture growth index, yields, shire census data, SOI, commodity prices	Farm cash income, costs, receipts, production
Savanna.au	Tree/Pasture/Fire/	Paddock or hillslope	Limited – still a research tool	Difficult	Obtaining necessary parameter data	Rainfall, temperature, humidity, wind speed, land type, fire frequency	Pasture dynamics, soil water, run-off
CCE	Animal production/ Grazing land management	Property	Currently limited	Difficult	Detailed maps of property land condition required	Ground/shrub cover, land types	Carrying capacity for individual paddocks
CENW_TG	Tree/grass ecosystem	Tree stand	Limited –still a research tool under development	Difficult	Detailed ecosystem responses can be simulated based on model complexity	Climate, tree layer structure, species composition, soil water, species attributes, fire regimes, grazing	Extensive output of all processes available
CSP	Carbon accounting	Regional	Limited	Easy	Obtaining necessary parameter data	Land use, rainfall, soil type	Soil and plant carbon

Model Name	Model type	Spatial Scale	How widely is the model used?	Ease of use in terms of parameter and data requirements	Key issues in ease of use or wider application	Key inputs	Key outputs
ENTERPRISE	Economic/animal	Enterprise/ Property	Limited – being refined for greater ease of use	Difficult		GRASP parameters, sale prices, costs, enterprise financial inputs	Gross margin, net profit, return, land condition, soil loss
GoldenWing GRASP	Tree/pasture	Point	Limited – still a research tool	Difficult	Obtaining necessary tree parameter data	As for GRASP	Tree dynamics, tree nitrogen and component biomass, plus GRASP outputs
GrazeOn	Animal production	Property	Limited	Difficult	Obtaining necessary tree parameter data	Area, animal intakes	Stocking rate
Kangaroo Model - QLD	Animal population	Property/ regional	Not Released	Easy	Parameters are hard-wired, no age or sex process	Rainfall, NVDI, harvest take-offs	Animal density
Kangaroo Model - NSW	Animal population	Property/ regional	Not Released	Easy	Obtaining necessary parameters on birth and death rates, no habitat component	Rainfall	Animal density, animal and pasture yields, MCDA values
RAB_POP	Animal population	Paddock	Not Released	Moderately difficult	Obtaining necessary parameter data for GRASP component, no spatial component	Temperature, pasture growth, stock rate	All variable values
Range-ASSESS	Carbon studies	Various	Not widely	Easy - no data input required	Knowledge of carbon layers	None	All processes may be provided as output
TREEGRASS-3D	Tree/grass water	Plot	Limited – still a research tool	Difficult	Obtaining necessary tree parameter data	Daily rainfall and radiation, intra-day air temperature and humidity	Light adsorption, tree and grass production, soil moisture
WALTER	Plant population	Plot	Limited – research tool	Moderately difficult	More detailed model being developed by Desert Knowledge CRC	Year type, time step, initial populations	Shrub demography
AridGrow	Plant growth	landscape	Limited				
EDYS	Vegetation dynamics	Landscape	Limited	Difficult	Obtaining necessary parameter data	Daily climate data, detailed soil characteristics, plant community structure, plant morphological and functional characteristics including roots, management inputs (stocking rate, vehicle use intensity, etc)	Plant community dynamics, net primary productivity, hydrological response
Feedman	Animal production/ economics	Property	Limited	Moderate	Skills required to run the package effectively	Paddock soil & pasture types, animal numbers, rainfall	Animal production, economics
GRIM	Climate index	Point	Limited	Easy	Old technology	Rainfall, temperature, evaporation, radiation	Climate indices, green days
IMAGES	Vegetation	Plot	Limited	Moderately difficult	Data for shrub dynamics	Wet days, carrying capacity, species groups	

Model Name	Model type	Spatial Scale	How widely is the model used?	Ease of use in terms of parameter and data requirements	Key issues in ease of use or wider application	Key inputs	Key outputs
LAMSAT	pasture/ animal production, soil erosion	Hillslope	Limited – new version recently developed	Moderately difficult	Limited to Daly basin of NT	Similar to GRASP	Pasture/ animal production, soil erosion
LANDASSESS	Land management	Paddock and property	Limited	Difficult	Obtaining necessary parameter & knowledge base data	Soil & vegetation types, stocking rates, rainfall	Land condition, production, economics
MulgaGRASP	Tree/pasture	Paddock	Not released	Difficult	Obtaining necessary parameter data, limited to Acacia shrublands	As for GRASP	As for GRASP, plus tree dynamics
SEESAW	Ecology/ sheep production	Regional	Limited	Difficult	No longer supported		Vegetation change, sheep production, economics
RangePack Paddock	Animal/pasture	Paddock	Limited	Easy	Obtaining necessary parameter data	Pasture types, paddock design	Grazing distribution/utilisation
Property Safe Carrying Capacity	Animal/pasture	Paddock	Limited	Easy	Obtaining necessary data on pasture types	Rainfall, pasture type, woody plant density	Property and paddock carrying capacity, pasture growth
GrassMan	Tree/ pasture management	Property	Limited	Relatively easy	Obtaining necessary data on pasture types	Seasonal rainfall, potential liveweight gain, pasture type	Tree, grass & animal production, economics
APSIM	Crop production	Plot/paddock	Widespread	Moderately difficult but excellent software engineering support	Obtaining necessary parameter for different soils and crop or pasture species though the major crops are now well parameterised	Soil characteristics, climate, agronomic management details	Crop plant production and crop yield, soil fertility
GrassGro	Pasture & animal production/ economics	Property/ regional	Widespread, as part of GRAZPLAN	Difficult	Limited to temperate zone, no fire component	Rainfall, pasture and animal type	Pasture and animal production
Arid River Flows	Hydrology	Catchment	Not released	Difficult	Hard-wired interaction between cells means it cannot be applied elsewhere	Rainfall	Stream flows, transmission losses
CLIMEX	Population dynamics	Regional/ national	Widespread	Moderately difficult	Restricted to effects of climate	Rainfall, temperature	Population densities or spread
IHACRES	Hydrology	Catchment	Widespread	Relatively easy	Daily rainfall at appropriate spatial density, changing land use or land condition not dynamic	Climate data, land use	Streamflow
IQQM	Hydrology	Catchment	Widespread	Moderately difficult	Obtaining necessary streamflow data	Rainfall and evaporation, streamflow, water allocation	Water quantity & quality, losses etc
Plague Locust Model	Locust population	Regional	Limited	Difficult	Integration of data from a number of sources, limited to locusts	Climate data, NDVI imagery, wind trajectories	Forecast of locust spread
PERFECT	Soil moisture	Paddock	Limited	Difficult	Necessary parameters for crop growth etc., no spatial capability	Climate data, soil characteristics	Crop yield, run-off, soil erosion/loss

Model Name	Model type	Spatial Scale	How widely is the model used?	Ease of use in terms of parameter and data requirements	Key issues in ease of use or wider application	Key inputs	Key outputs
RAINMAN	Rainfall probability	Point	Widespread	Easy	Limited only by available rainfall data	Location, rainfall	Rainfall statistics, seasonal rainfall forecasts, drought indicators etc
SedNet	Hydrology	Catchment	Limited in user number but widespread in application	Difficult	Detailed parameterisation is necessary	Soil types, terrain, climate, vegetation cover	Sediments & nutrient discharges
SHEEPO	Sheep production	Point	Limited – no longer in active use	Moderately difficult	Limited to temperate zone and has no tree or shrub component		Sheep & pasture production
SLIM	Environmental economics	Regional	Limited - still a research tool	Difficult	Detailed parameter set required	Soil type, geology, rainfall, terrain, land use	Erosion, nutrient loss, water yield, salt loadings, economic optimisation
SWAT	Hydrology	Catchment	Limited	Moderately difficult		Land use, climate data, soil type, vegetation	Water, sediment, nutrient & pesticide yields
SWIM	Hydrology	Plot	Limited though commercially available	Moderately difficult	principally to do with solute transport, sensitive to some parameters	Soil type	Run-off, infiltration, solute transport, deep drainage, leaching

Appendix 1. Short biographies of key project personnel

Andrew Ash is leader of the Rangelands and Savannas Program in CSIRO Sustainable Ecosystems. This program has over 50 staff working in central and northern Australia and Andrew is responsible for business development, project and financial management and people development within the program, and is a member of the Divisional Executive Committee. Andrew has approximately 20 years research experience in northern Australia, with emphasis on sustainable grazing management and climate impacts in the rangelands. This work has involved using models of climate, pasture growth, animal production and enterprise economics and Andrew has contributed significantly to the development of GRASP and herd economics models and pilot-tested the US model, EDYS (Ecological Dynamics Simulation Model), for use in management of military training areas in northern Australia. Andrew is a member of the Continuing Committee of the International Rangelands Congress.

John Ludwig is the theme leader on landscape ecology and health in the Tropical Savannas Management Cooperative Research Centre where he coordinates and integrates project activities in this CRC, working closely with 11 project leaders and other project staff. Many of these projects include simulation modelling. John has conducted research in rangelands for over 30 years, including research in Australia, western USA, northern Mexico, and South Africa. This research includes the development and use of Australian rangeland simulation tools such as Shrubkill (with Neil MacLeod), Seesaw (with Steve Marsden) and, most recently, Savanna.Au (with Adam Liedloff and Mike Coughenour).

Adam Liedloff is currently developing process based ecological models for CSIRO Sustainable Ecosystems and the Tropical Savannas Management CRC. These models are being used to develop an understanding of the effects of various management decisions such as burning and grazing on the tropical savannas of northern Australia. Prior to this, Adam developed a population dynamics model for research and undergraduate course work at Queensland University of Technology and a simulation model of the estimation techniques of rodent damage to sugar cane in north Queensland.

John McIvor is the Research Group Leader of the Brisbane group of the Rangelands and Savannas Program in CSIRO Sustainable Ecosystems. He has over 30 years experiences working in the rangelands of northern Australia with particular emphasis on management for production and conservation of resources. During this time he has been involved in the development of simple biological (e.g. plant establishment) and economic (e.g. whole property beef production) models, and the application of other models (e.g. GRASP and spreadsheet economic models) to predict the impacts of management on property performance.

Cam McDonald is a member of the Brisbane group of the Rangelands and Savannas Program in CSIRO Sustainable Ecosystems. He has over 30 years experiences working in the rangelands of northern Australia with emphasis on agronomy of grazed pastures, particularly legume population dynamics, monitoring pasture yield and composition, animal production and data analysis, simulation modelling of animal/pasture systems. He has developed models of the seed dynamics of legumes and animal production from pastures which have been linked with economic models to examine impacts of potential changes on ecosystem performance.

Mark Stafford Smith is CEO of the Desert Knowledge CRC, a partnership among 28 organisations that he was instrumental in establishing. He has had extensive program, project and staff management experience including 5 years as Program Leader of CSIRO's Centre for Arid Zone Research in Alice Springs; in this role he was also part of the Divisional Executive Committee, and led the research and management of the rangelands' component of the Division's work. He has worked in desert areas around the world since 1975, in Australian rangelands since 1980, and has an intimate understanding of the issues of grazing and sustainability. He has been responsible for developing several models of rangelands and interacting on many more, including detailed chenopod shrubland growth and sheep behaviour process models, the RANGEPACK series, and a variety of smaller bioeconomic models.

Mark Howden is leader of a team dealing with systems ecology in the Agricultural Landscapes Program in CSIRO Sustainable Ecosystems. Mark has over 20 years research experience in rangeland and grassland systems in Australia. The core theme of his work is taking a systems approach to understanding the interactions between management decisions, climate and ecosystem dynamics so as to provide information to industry and governments enabling development of more resilient systems and institutions. A core tool in this work is simulation modelling which integrates these factors. Mark has worked with staff from many organisations who also undertake this work, using their models, developing and testing new modelling capabilities and extending the analyses to include climate change and carbon dioxide effects as well as greenhouse gas emission budgets.

Greg McKeon is a Principal Scientist with the Department of Natural Resources and Mines, with particular interests in systems ecology, systems modelling and climate variability research. He played a leading and instrumental role in the development of the GRASP model of pasture growth for northern Australia. Greg has nearly 30 years experience in the rangelands of northern Australia and much of his has involved the development and application of simulation models.

Appendix 2. Template for model descriptions with all criteria used for Category I and II models and only overview criteria used for Category III and IV models

Model description

A. OVERVIEW

1. **Title** – give model acronym and 1 line title (e.g. GRASP, native grass production model)

2. **Purpose/Objective** – single paragraph describing the primary purpose for which the model was built and any secondary uses or additions to the model.

3. **Keywords** –give keywords (e.g. grazing, rangeland sustainability, economics, plant growth) describing the primary functions of the model

4. **Key contact/s** – give the key contact/s (name, telephone number, email address) and their Institution, and list any other key personnel associated with the model.

5. **Model status** – briefly state whether the model is fully operational (i.e. fully tested and validated) or still under development. If under development give the institutions/external bodies supporting the development.

6. **Ownership/Availability** – give the IP for the model; specify the availability (e.g. freely available, under licence, to collaborators); are key data sets available?

7. **History of development** – single paragraph describing when model development was initiated; what expansions (if any) have been made and when; who have been the key developers.

8. **Documentation** – list any published references that describe the model; is there any user documentation available?

9. **Links to other models** – single paragraph describing any cases where the model has been linked to other models (linked GRASP to HERDECON); outline any inter-model comparisons that have been performed.

10. **Objective assessment** – paragraph (or 2) objectively describing the strengths, weaknesses and limitations to the model; indicate what level of effort would be required to overcome any limitations/weaknesses and/or make it more useful.

B. DETAILED MODEL DESCRIPTION

If the information requested in items 11-18 is available in a <u>readily available</u> key reference then the reference can be given instead.

11. **Model features** – give the type of code used (e.g.. Fortran, C), the user interface; whether the model has spatial or temporal capability, is it mechanistic or empirical, time-step, etc.

12. **Model processes** – e.g. temperature, radiation, plant growth, liveweight gain

13. **Minimum data sets required** – describe the type (e.g daily rainfall, temperature) and availability of critical data sets required for input

14. **Parameter sets** – list and describe 15-20 key parameters the end-user will be able to (need to) change in order to appropriately run the model; briefly outline other parameters the end-user is able to change if they have the relevant information; give a general outline parameters that are hard-wired in the model.

15. **Development/Validation data** – briefly outline the source of the data used for development and validation of the model (e.g. grazing trials, cutting trials, literature) and list any key references to this data.

16. **Sensitivity analyses** – describe what sensitivity or optimisation analyses have been carried out, and whether the model generates any uncertainty values.

17. **Model output** – describe the key or most commonly used outputs from the model; list other outputs that may be available

18. **Application** – single paragraph describing the application of the model; another paragraph describing any simulation studies carried out with the model, giving key references.

Appendix 3. Contacts database for the custodians of the various models.

Model	Category	Contact Name	Phone number	Organisation	Location	Email address	Web address
AussieGrass	1	John Carter	(07) 3896 9588	Dept Natural Resources & Mines	80 Meiers Rd, Indooroopilly Qld 4068	John.Carter@nrm.qld.gov.au	http://www.longpaddock.qld.gov.au/AboutUs/Publications/ByType/Reports/AussieGRASS-FinalReport/FullReport.pdf
Breedcow/Dynama	1	Bill Holmes	(07) 4722 2663	Dept Primary Industries & Fisheries	PO Box 1085, Townsville Qld 4810	Bill.Holmes@dpi.qld.gov.au	http://dpi.qld.gov.au/breedcowdynama/2816.html
Century	1	John Carter	(07) 3896 9588	Dept Natural Resources & Mines	80 Meiers Rd, Indooroopilly Qld 4068	John.Carter@nrm.qld.gov.au	
Flames	1	Adam Liedloff	(08) 8944 8446	Tropical Ecosystem Research Centre	Vanderlin Dr, Berrimah NT 0828	adam.liedloff@csiro.au	
GRASP	1	Greg McKeon	(07) 38969548	Dept Natural Resources & Mines	80 Meiers Rd, Indooroopilly Qld 4068	Greg.Mckeon@nrm.qld.gov.au	
Growest	1	Tim Brinkley	(02) 6272	Bureau of Rural Sciences	GPO Box 858, Canberra, ACT 2601	tim.brinkleyl@brs.gov.au	
HerdEcon/ RiskHerd	1	Mark Stafford Smith	(08) 8950 7162	Desert Knowledge CRC	PO Box 2111, Alice Springs NT 0871	Mark.StaffordSmith@csiro.au	
BBSafe	1	Dave Cobon	(07) 4688 1151	Dept Primary Industries & Fisheries	203 Tor St, Toowoomba Qld 4350	David.Cobon@dpi.qld.gov.au	
agFIRM	2	Phil Kokic	(02) 6272 2603	Aust. Bureau Agric. & Resource Economics	GPO Box 1563, Canberra, ACT, 2601	phil.kokic@abare.gov.au	
Savanna.au	2	Adam Liedloff	(08) 8944 8447	Tropical Ecosystem Research Centre	Vanderlin Dr, Berrimah NT 0828	adam.liedloff@csiro.au	
CCE	2	Dave Cobon	(07) 4688 1151	Dept Primary Industries & Fisheries	203 Tor St, Toowoomba Qld 4350	David.Cobon@dpi.qld.gov.au	
CENW-TG	2	Guillaume Simioni	(02) 6281 8406	CSIRO Forestry and Forest Products	Banks St, Yarralumla, ACT	guillaume.simioni@csiro.au	
CSP (Carbon Sequestration Predictor)	2	Kelvin Montagu	(02) 9872 0146	R&D Division, State Forest of NSW	121 Oratava Av., West Pennant Hills 2125	kelvinm@sf.nsw.gov.au	http://www.forest.nsw.gov.au/env_services/ess/default.asp#carbonlink
ENTERPRISE	2	Andrew Ash	07 3214 2346	CSIRO Sustainable Ecosystems	306 Carmody Rd, St Lucia Qld 4067	Andrew.Ash@csiro.au	
Golden-Wing GRASP	2	John Carter	(07) 3896 9588	Dept Natural Resources & Mines	80 Meiers Rd, Indooroopilly Qld 4068	John.Carter@nrm.qld.gov.au	
GrazeOn	2	Dave Cobon	(07) 4688 1151	Dept Primary Industries & Fisheries	203 Tor St, Toowoomba Qld 4350	David.Cobon@dpi.qld.gov.au	
Kangaroo dynamics - Qld	2	Tony Pople	(07) 3365 4831	Dept of Zoology	Univ. of Qld, St Lucia Qld 4067	tpople@zen.uq.edu.au	
Kangaroo dynamics - NSW	2	Steve McLeod	(02) 6391 3810	Vertebrate pest Research Unit, NSW Agric.	Forest Road, Orange NSW 2800	steven.mcleod@agric.nsw.gov.au	
RAB_POP	2	Joe Scanlan	(07) 4688 1243	Robert Wicks Pest Animal Research Centre	Toowoomba, Q 4350	joe.scanlan@nrm.qld.gov.au	
RANGEASSESS	2	Michael Hill	(02) 6272 5317	Bureau of Rural Sciences	GPO Box 858, Canberra, ACT 2601	Michael.Hill@brs.gov.au	http://www.affa.gov.au/content/output.cfm?ObjectID=F715697D-62CA-49BF-89A3F707101708E9
TREEGRASS	2	Guillaume Simioni	(02) 6281 8406	CSIRO Forestry and Forest Products	Banks St, Yarralumla, ACT	guillaume.simioni@csiro.au	
WALTER	2	Ian Watson	(08) 9690 2179	Dept of Agriculture, Western Australia	PO Box 483, Northam, WA, 6401	iwatson@agric.wa.gov.au	
AridGrow	3	John Ludwig	(07) 4091 8799	CSIRO Sustainable Ecosystems	Maunds Rd, Atherton, Q 4883	john.ludwig@csiro.au	
EDYS	3	Andrew Ash	(07) 32142346	CSIRO Sustainable Ecosystems	306 Carmody Rd, St Lucia Qld 4067	Andrew.Ash@csiro.au	
FeedMan	3	Ken Rickert	0429 326 269	formerly University of Queensland	The University of Queensland, Gatton Camp	janrickert@bigpond.com	
Grim	3	Cam McDonald	(07) 3214 2289	CSIRO Sustainable Ecosystems	306 Carmody Rd, St Lucia Qld 4067	cam.mcdonald@csiro.au	
Images	3	Z.G.Yan & K.M.Wang	(08) 9368 3333	WA Dept Agriculture		enquiries@agric.wa.gov.au	
Lamsat	3	Mohammed Dilshad	(08) 8999 5511	NT Department of Infrastrucure, Planning and E	GPO Box 1680, Darwin, NT 0801		
LandAssess	3	Jenny Bellamy	(07) 3214 2345	CSIRO Sustainable Ecosystems	306 Carmody Rd, St Lucia Qld 4067	jenny.bellamy@csiro.au	
MulgaGRASP	3	John Carter	(07) 3896 9588	Dept Natural Resources & Mines	80 Meiers Rd, Indooroopilly Qld 4068	John.Carter@nrm.qld.gov.au	
SeeSaw	3	John Ludwig	(07) 4091 8800	CSIRO Sustainable Ecosystems	Maunds Rd, Atherton, Q 4883	john.ludwig@csiro.au	
RangePack Paddock	3	Mark Stafford Smith	(08) 8950 7162	Desert Knowledge CRC	PO Box 2111, Alice Springs NT 0871	Mark.StaffordSmith@csiro.au	
Property Safe Carrying Capacity	3	Terry Beutel	(07) 4654 4282	Queensland Department of Primary Industries a	PO Box 282, Charleville, QLD 4470	terry.beutel@dpi.qld.gov.au	
GrassMan	3	Joe Scanlan	(07) 4688 1243	Robert Wicks Pest Animal Research Centre	Toowoomba, Q 4350	joe.scanlan@nrm.qld.gov.au	
APSIM	4	APSRU	(07) 4688 1394	CSIRO/QDPI	203 Tor St, Toowoomba Qld 4350	apsru@apsru.gov.au	http://www.apsru.gov.au/apsru/Products/apsim.htm
GrassGro	4	John Donnelly	(02) 6246 5106	CSIRO Plant Industry	GPO Box 1600, Canberra, ACT 2601	john.donnelly@csiro.au	
Arid river flows	4	Justin Costelloe	(03) 8344 7238	Dept. Civil & Env. Eng., Univ. of Melbourne	Victoria, 3010	j.costelloe@civag.unimelb.edu.au	
CLIMEX	4	Rob Sutherst	(07) 3214 2707	CSIRO Entomology	120 Meiers Rd, Indooroopilly Q 4068	bob.sutherst@csiro.au	http://www.ento.csiro.au/research/pestmgmt/IPMModellingNetwork/software2.htm
IHACRES	4	Barry Croke	(02) 6125 0666	Integrated Catchment Assessment & Managem	ANU, Canberra	Barry.Croke@anu.edu.au	http://www.mpassociates.gr/software/environment/ihacres.html
IQQM	4	Paul Pendlebury	(02) 9895 7480	NSW Department of Infrastructure and Planning		Paul.pendlebury@dipnr.nsw.gov.au	http://www.nrm.qld.gov.au/wrp/pdf/border/iqqm_14697.pdf
Locust model	4	David Hunter	(02) 6272 5076	Plague Locust Commission	12 Mildura St, Fyshwick, Canberra ACT	david.hunter@affa.gov.au	
PERFECT	4	APSRU	(07) 4688 1394	CSIRO/QDPI	203 Tor St, Toowoomba Qld 4350	apsru@apsru.gov.au	
RAINMAN	4	Jeff Clewett	(07) 4688 1244	Dept Primary Industries	203 Tor St, Toowoomba Qld 4350	Jeff.Clewett@dpi.qld.gov.au	http://www.dpi.qld.gov.au/rainman/
SedNet	4	Scott Wilkinson	(02) 6246 5774	CSIRO Land & Water	GPO Box 1666, Canberra ACT 2601	scott.wilkinson@csiro.au	
Sheepo	4	Malcolm McPhee	(02) 4640 6333	NSW Agriculture	Menangle, 2570, NSW, Australia	malcolm.mcphee@agric.nsw.gov.au	
SLIM	4	Stefan Hajkowicz	(07) 3214 2327	CSIRO Sustainable Ecosystems	306 Carmody Rd, St Lucia Qld 4067	Stefan.Hajkowicz@csiro.au	
SWAT	4	Jeff Arnold		ARS-Temple		jgarnold@spa.ars.usda.gov	http://www.brc.tamus.edu/swat/
SWIM	4	Keith Bristow	(07) 4753 8596	CSIRO Land & Water	University Dr, Townsville Q 4810	keith.bristow@csiro.au	