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Improving grazing management using the GRASP model

Abstract

The objectives of the project were to: (1) develop an updated and fully documented version of the pasture growth model GRASP so that it can be used by pasture scientists across northern Australia; (2) support the model with a comprehensive parameter library for different land-types in northern Australia; and (3) train more than twelve pasture scientists in the use of the model and its supporting tools. In the project the following tasks were successfully achieved:

1) Improved computing code and modelling environment were developed;
2) Approximately forty pasture scientists were trained in three major workshops in the use of the model and the new interfaces;
3) The model was improved by the addition of alternative runoff models and also sub-models addressing the varying dilution of available nitrogen by pasture;
4) New pasture growth datasets and historical grazing trial data from across northern Australia were added to the database;
5) New approaches to calculate animal intake and utilisation in grazing trials were demonstrated;
6) Parameter sets were developed for about 250 land-types in Queensland and close liaison was established with the pasture science teams in the Northern Territory and Western Australia who are conducting similar exercises;
7) The pasture growth model GRASP has been linked to the CSIRO SE herd/economics model ENTERPRISE;
8) A more formal network of pasture scientists across states and institutions was established; and
9) The results of the model development have been communicated through the Grazing Land Management education package (GLM), on-line model documentation, workshops for pasture scientists, and publications by CSIRO SE.

The achievements of the project provide a basis and a legacy for the future development of models of pasture growth and their application to the northern Australian grazing industry.

Executive Summary

Graziers in northern Australia face a major challenge of matching stocking rate to pasture growth to achieve sustainable animal production. Thus there has been an integral need to supply the grazing community, supporting advisors and agencies with calculations of pasture growth for different land-types and climatic conditions. A major challenge that pasture scientists face in addressing this need is to estimate pasture growth across a range of land-types. Addressing this challenge has involved the collection and collation of data from field studies including pasture growth exclosures and grazing trials. Over the last 30 years, it has also involved the development of simulation models of pasture growth to allow the results from field trials to be extrapolated in time and space; and to simulate the different effects of grazing management decisions on the pasture resource.

The simulation model GRASP is a soil-water, pasture-growth model developed for northern Australia and rangeland pastures. The GRASP model has been developed over many years by a range of researchers and hence, brings together much of our existing understanding of rangeland system processes. Although GRASP has been used in many applications since the early 1980s, there has been a need to provide more up-to-date computing code, model interfaces and a library of parameter sets, as well as training for pasture scientists in its use to meet industry needs. Addressing these issues in this project will ensure that the GRASP model remains a valuable asset for the grazing systems research community.

Thus the objectives of the project were to:

1) Develop an updated and fully documented version of the pasture growth model GRASP so that it can be used by pasture scientists across northern Australia;
2) Support the model with a comprehensive parameter library for different land-types in northern Australia; and
3) Train more than twelve pasture scientists in the use of the model and its supporting tools.

To achieve these objectives the project was divided into nine major tasks, which were successfully achieved by the GRASP modelling team:

1) Improved computing code and modelling environment were developed;
2) Approximately forty pasture scientists were trained in three major workshops in the use of the model and the new interfaces;
3) The model was improved by the addition of alternative runoff models and also sub-models addressing the varying dilution of available nitrogen by pasture;
4) New pasture growth datasets and historical grazing trial data from across northern Australia were added to the database;
5) New approaches to calculate animal intake and utilisation in grazing trials were developed and demonstrated;
6) Parameter sets were developed for over 250 land-types in Queensland and close liaison was established with the pasture science teams in the Northern Territory and Western Australia who are conducting similar exercises;
7) The pasture growth model GRASP has been linked to the CSIRO SE herd/economics model ENTERPRISE;

8) A more formal network of pasture scientists across States and institutions was established; and
9) The results of the model development have been communicated through the Grazing Land Management education package (GLM), on-line model documentation, workshops for pasture scientists, and publications by CSIRO SE.

Improved computing code and model interface

A new updated version of the GRASP model code (CEDAR version) adheres to the highest standards of computer programming design. Previous versions of the model were incrementally developed through the 1980s and 1990s and hence, a major revision was needed to upgrade the standard of computing code and design. These model updates and improvements are accessible as web downloads. The developments in the code are fully documented and the model is supported by on-line documentation. The development of a consistent high quality set of code has allowed other developers and users to contribute and include the model in other applications. Each equation in the model is described in a comprehensive technical manual along with a wide-ranging glossary of terms.

There are various ways of running the GRASP model including the use of control files and factorial analyses, and through a user-friendly interface known as the GRASP Calibrator. The GRASP Calibrator includes the main features that most users need, namely:

- The capacity to easily run simulations for different land-types and climate stations;
- Graphical display of all variables simulated by the model including soil water, hydrological components, pasture growth, dry matter flow, nitrogen uptake and concentration, tree water use and other tree attributes, stocking rate and other grazing variables, and aspects of degradation risk (utilisation and soil loss);
- Conditional probability analysis of simulated variables especially pasture growth;
- Graphical comparison of observed and simulated variables with statistical analysis which are particularly important for analysis of pasture growth and grazing trial data; and
- Growth analysis in which measured pasture growth is graphically compared to a range of variables (such as ‘simulated growth index’), hence facilitating parameterisation of the dataset.

The GRASP Calibrator achieves a major objective of the project being the provision of a consistent and up-to-date modelling environment for pasture scientists across northern Australia.

Training pasture scientists in the use of GRASP

Using the above capability, three major training workshops (each of three days duration) were conducted at both Katherine (1 workshop) and Brisbane (2 workshops). Approximately 40 pasture scientists, mainly working with the northern Australian beef industry, were trained. The scientists represented a number of states and institutions (Queensland Department of Primary Industries and Fisheries, Queensland Department of Natural Resources and Water, Northern Territory Department of Primary Industry, Fisheries and Mines, Western Australia Department Agriculture and Food, New South Wales Department of Primary Industries, CSIRO SE and University of Queensland).

An independent evaluation was conducted using self-assessment of the skills learnt during the workshop. The collective results from the self-assessments of the 40 participants were:

- They had approximately 595 years (range 0 months to 50 years) of association with the beef industry and 313 years (range 0 months to 30 years) with modelling;
- 22 (55%) of the participants indicated that they had attained a working knowledge of most (two-thirds or more) of the skills required to be operational in the use of the model (i.e. simulating pasture growth for different land-types using the GRASP Calibrator interface); and
- 14 (35%) of the participants indicated that they had obtained a working knowledge of all the tasks needed to carry out their own simulations; and
- five participants indicated that they had attained a very high level of expertise thus providing a wider base for the continued use and development of GRASP.

Improving the model, collating datasets and analysing grazing trials

To support the major application, namely the simulation of pasture growth for different land-types, the model development included new sub-models for:

- Runoff for different soil types such as those that have surface sealing or impermeable layers at depth;
- Variable dilution of available nitrogen that occurs at the end of the growing season;
- New approaches to calculating animal intake and utilisation in grazing trials; and
- Linking model outputs such as simulated green cover to remote sensing products (e.g. NDVI).

Library of land-type parameters

In this project and supporting projects, C. Chilcott and colleagues have developed parameter sets for over 300 different land-types across 13 different catchments or unique pastoral zones. Land-types were defined by pasture composition and growth characteristics, soil structure, fertility and texture, tree species and density. Model parameters were derived from this information. Thus a major achievement of the project is the initial preparation of a large number of parameter sets describing soil and plant information for different land-types across Queensland.

Other achievements of the project include: linking model outputs to the CSIRO SE herd/economics model ENTERPRISE; and establishing of a network of pasture scientists across states and institutions using a consistent modelling environment.

The improvements in the model from this project provide a sound basis for the future development of models of pasture growth and their application to industry.

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1 Background

1.1 Background

The overall theme of the project NBP.338 Improving Grazing Management using the GRASP Model is, how to achieve the ‘best’ grazing management in a variable climate. The theme is important because it gives the context in which the GRASP model is being developed and applied. Modelling projects which do not have clear themes, objectives and applications are likely to fail because of lack of focus. As discussed below this project has clear applications and industry support as well as a network of scientists motivated to apply the model. Thus the major task of the project was to build a better modelling environment (better code and associated interfaces) and to train scientists in northern Australia in the use of the model. From a grazing industry perspective, the major applications of the GRASP model are detailed later in this report (Section 1.1.3).

1.1.1 Brief review of modelling philosophy

Before describing GRASP in detail, it is important to reaffirm why pasture scientists build and use models. The major reasons are to:

1) Assist decision makers to achieve profitable and sustainable use of the grazed resource;
2) Conduct a rigorous systems analysis of experimental trials and the management of grazing properties;
3) Extrapolate research results in time and space;
4) Conduct simulation experiments to show different effects of biophysical processes and managerial decisions; and
5) Formally calculate optimal or ‘best’ managerial decisions.

Modelling projects have been supported in agriculture in general because they have provided a way of: achieving the above objectives, and facilitating the application and extrapolation of the public investment in experimental field trials. However, models are, by definition, only abstractions of reality. They are limited by not being able to represent the complete complexity of the biophysical components of the grazing system. Agricultural models are also limited in their application because of the lack of confidence that the community (e.g. users and graziers) have in the modelling approach. Modelling projects have been successful in direct application to the grazing industry where particular attention has been paid to the ‘people-side’ of the application (i.e. ‘liveware’ support). Successful examples include carrying capacity project in the South West Strategy (Johnston *et al.* 1996); and Buxton case studies by with individual graziers (Buxton and Stafford Smith 1996).

1.1.2 History of GRASP leading to the project

To meet the above objectives, GRASP was initially developed in 1978 and various applications have been conducted through the 1980s and 1990s (Rickert *et al.* 2000). The major applications since 1995 have been in the assessment of Drought Exceptional Circumstances at a national scale (Carter *et al.* 2000). As a consequence, the application of GRASP to grazing trials, and the training of scientists in its use, have been conducted on an ad hoc basis and have not been formally supported by external industry funding since the completion of the two RIRDC projects in 1997 (Day *et al.* 1997, McKeon *et al.* 1998). In the early 2000s it was apparent that there was a major need to organise the application of and training with GRASP on a more formal basis which led to the formation of the current project NBP.338 Improving grazing management using the GRASP model.

The partners in the project NBP.338 were: Meat and Livestock Australia (MLA), Queensland Department of Natural Resources and Water (QNR&W), Queensland Department of Primary Industries and Fisheries (QDPI&F) and CSIRO Sustainable Ecosystems (CSIRO SE). It was important in a multi-institutional project such as NBP.338 to document what each of the partners wanted to achieve at the start of the project. The following paraphrased statements were made at the start of the project (early 2005) and reflected expected outcomes of the project. For example, MLA wanted: a pasture growth model with 'all the trimmings' (i.e. code, documentation, modelling environment, library parameter sets, analysis of MLA supported grazing trials); and more than 12 pasture scientists trained in the model so that there is a wider network for modelling support and application.

CSIRO SE saw great value in the continued development of GRASP for application in improved grazing management across northern Australia. CSIRO SE planned to use the enhanced GRASP model in testing of different grazing strategies and grazing systems at an enterprise scale that includes links to economics. This would allow detection of economic and environmental trade-offs for different grazing strategies. Another important application of GRASP for CSIRO SE was in evaluating climate interactions with grazing; this included using GRASP to extrapolate the results of a climate change experiment across the savannas of northern Australia and in testing improved seasonal forecasts.

Some of the issues involved in the project were discussed at the Project Steering Committee meeting in February 2005. Some example comments from the collaborating agencies are given below:

- M. Quirk (QDPI&F) highlighted the need to have a formal modelling project given that modelling expertise had been accessed project by project in the past. The previous versions of GRASP were very hard to use. QDPI&F needed land-type pasture growth output now (2005) for a wider audience being delivered through the GLM package thus allowing the opportunity for increased grazier uptake of the knowledge. The major deadline for QDPI&F's analysis was the end of June 2005.
- A. Ash (CSIRO SE) said that GRASP had been used as part of a model of the whole grazing enterprise system. Given the diverse land-types across northern Australia and the complexity of the biophysical processes it was important to recognise that GRASP cannot 'do it all' and that other models, such as Savanna AU and FLAMES, are required to address other components of the grazing system. Thus it is important to recognise that GRASP was not for everybody and therefore it was important not to build up the expectations in this regard.
- K. Brook (QNR&W) indicated that the issues were how to address grazing management for improved sustainability. He saw the importance of PaddockGRASP as the way of addressing these issues at a property scale. GRASP was important for QNR&W in terms of looking at the potential of seasonal climate forecasts and the impact of climate change. Emerging issues for QNR&W to be kept in mind included 'carbon' and the rural leasehold land strategy.

It was also important at the start of the project to clarify what the GRASP model is – and what it is not. GRASP is a one-dimensional soil water and pasture growth model which has been run at scales of a single point, paddock, 5km pixel, land-type and pasture community. It simulates some of the components of the grazing system (i.e. hydrology, above-ground dry matter and nitrogen flow, animal production). Its inputs include climate data, biophysical parameters and grazing management decisions such as burning and stocking rate. GRASP is not a landscape model nor is it a model of the complete water/carbon/nitrogen cycle. The representation of cattle and sheep production is simplistic (i.e. annual production) and GRASP does not include herd-stock dynamics or cash flow.

In terms of computer code, at the start of this MLA project, the model GRASP existed in several forms: (1) 'Spaghetti', a user unfriendly version incorporating all modelling developments and applications since 1978; (2) CedarGRASP based on new coding done in 1995 by N. Flood with small additions by M. Stafford Smith; and (3) 'AussieGRASS' run as a spatial model by J. Carter. As described in the following progress report a major task has been the development and testing of CedarGRASP code to incorporate the developments that have occurred in both Spaghetti and AussieGRASS versions.

1.1.3 Applications

The explicit hypothesis underpinning GRASP is that a set of model parameters describing a particular soil/pasture/woodland situation (e.g. available soil water range, potential nitrogen uptake) can be derived from short-term field data and then used to extrapolate across time, space and management options. To this end, the major applications of GRASP since 1980 have been:

1. **Historical pasture growth.** Using over 100 years of daily climate data and a constant parameter set, GRASP is able to simulate the daily components of the grazing system (hydrology, carbon flow, resource condition and animal production). The model parameter set is derived by calibration with field measurements. Thus GRASP has provided a useful approach of extrapolating short-term field measurements from either plot (1 to 5 years) or grazing trial (5 to 20 years) studies over a much longer period of historical climate variability. These historical simulations have formed the basis for the analysis of safe carrying capacity (e.g. Johnston *et al.* 1996, Hall *et al.* 1998, McKeon *et al.* 2000).

2. **Conditional Probability using current conditions.** The simulation of historical pasture growth has been used in a conditional probability analysis by resetting each year on a specified date (e.g. 1st November) soil moisture and pasture variables to current conditions (e.g. dry soil and near zero pasture biomass). This approach provides an assessment of the combined impact of current conditions and historical variability (Hacker *et al*. 2006, Alemseged *et al.* 2006).

3. **Current climate risk assessment.** The simulation studies conducted as part of (1) and (2) above can be used to make a climate risk assessment using seasonal climate forecasting systems which divide the historical record into different year types. The simplest and most relevant year-types for eastern Australia are based on the El Niño Southern Oscillation phenomenon (El Niño, Neutral and La Niña, McKeon *et al.* 2004). Thus in this application GRASP has been used to make climate risk assessments or 'forecasts of pasture growth'. The operational AussieGRASS version of GRASP simulates the grazing system for 185 pasture communities across Australia allowing projections of pasture growth to be made from the inputs of up-to-date climate data and likely future seasonal climate developments (based on historical SOI based year-types).

4. **Grazing trial analysis.** A major public investment has been made in grazing trials in which different grazing management treatments have been used. The most typical type of grazing trial has involved different levels of stocking rate or utilisation levels to investigate the impact on animal production and resource condition. GRASP has been used to analyse these grazing trials by representing each paddock or treatment in the trial (Day *et al*. 1997). From the measured pasture and animal production data, model parameters have been derived and sub-models of how these parameters change with grazing pressure have been developed. The model parameters have then been used to allow a range of grazing management decisions to be simulated thus allowing the grazing trial results to be extrapolated over longer time periods and grazing management options (e.g. McKeon *et al.* 2000).

   In cases where the grazing trial results can be extrapolated to other spatial locations (e.g. similar soils and vegetation), the derived model parameters can be used to investigate the implications for other climatic environments. By conducting many simulation studies (Ash *et al.* 2000, Stafford Smith *et al.* 2000) optimal stocking rate strategies have been derived either to maximise production (measured in terms of drought risk, animal production or dollars) or minimise degradation risk (in terms of soil loss, species composition change, and frequency of burning to control woody plants).

5. **Land-type combinations**. A major application of GRASP has been the calculation of pasture growth for a particular land-type using historical climate data. The procedure used so far has involved calibrating the model to a few years of measured pasture growth collected using the GUNSYNpD or SWIFTSYNpD methodology (Day *et al.* 1997), and then using historical climate data to simulate pasture growth with these model parameters over a longer time period. As part of the NBP.338 project, an approach was also developed in which model parameters were derived from land resource information describing soil and plant attributes. The simulations of pasture growth from GRASP have been used in the Grazing Land Management (GLM) education package (MLA 2003, Quirk and O'Reagain 2003).

6. **Climate change impacts including carbon dioxide.** GRASP has been used to investigate the impact of current and future climate change including increases in carbon dioxide (CO_2) on the grazing system (Hall *et al.* 1998, Howden *et al.* 1998). The change in model parameters with CO_2 has been derived from small scale experiments involving a few levels of CO_2 as well as consensus views on how pasture communities are likely to respond to increased CO_2.

7. **Links to other models such as HerdEcon, ENTERPRISE and GoldenWing**. GRASP has been linked to other models, for example HerdEcon (Stafford Smith *et al.* 2000). Output of GRASP has also been used as the input to other models for example ENTERPRISE (MacLeod *et al.* 2001, MacLeod *et al.* 2004). J. Carter has developed a woodland dynamic model building on GRASP (e.g. GoldenWing). As described later, the new model has been coded in a way to provide flexibility for other users to incorporate GRASP in their modelling activities.

The above applications are important as they provide the major focus for the training of other scientists in the use of GRASP. They also unify the development of software interfaces so that scientists can easily use the model for similar applications. Future applications and hence the design of the modelling environment will require some flexibility and open-endedness.

1.1.4 Pasture growth for different land-types in GLM

A challenge for pastoral land managers in northern Australia is to match livestock stocking rates to available forage. The need for better management recommendations has, in part, been driven by an increased recognition of the relationship between poor land management and negative off-site impacts, such as soil erosion and the decline in water quality of rivers and adjacent near-shore areas. Northern Australia's rangelands (Queensland, Northern Territory and northern Western Australia) are characterised by high spatial and temporal variability which reduces the effectiveness of broad managerial recommendations without the benefit of local experience or grazing trial information. Simulation modelling of pasture production is needed to provide managers with locally relevant stocking rates and management recommendations. Estimations of pasture growth based on locally relevant land-types and climatic conditions are provided to graziers and their advisors through the GLM education package (MLA 2003).

1.1.5 Conclusion

The most important current application of GRASP is the simulation of pasture growth for different land-types and the calculation of safe carrying capacity for use in GLM. This project specifically addresses this need in terms of the development of better models; better accessibility to the model and parameter sets for pasture scientists; and the preliminary calculation of utilisation from grazing trials to better estimate safe utilisation rates.

2 Project objectives

1) Develop an updated and fully documented version of GRASP that:
   - Will be able to be used by scientists and extension officers to simulate pasture production and assessment of degradation risk for most land-type groupings relevant to beef cattle grazing in northern Australia;
   - Contain a comprehensive parameter library which enables it to be customized for use in most major beef grazing land-types in northern Australia;
   - Will be able to be used in the development, delivery and application of Grazing Land Management (GLM) and associated decision support packages for most regions in north Australia.
2) Train more than 12 officers to be able to use GRASP, parameterise the model, run simulation studies, analyse grazing trial data and develop materials for GLM and decision support packages.

Structure of the project and the final report

To achieve the above objectives nine separate tasks were developed as approved by the Project Steering Committee. The following method and results sections report on the procedures used and the results from each task.

Task 1: Developing a new computer code and interface tools to use the GRASP model.

Task 2: Training pasture scientists in the use of the interface and the model.

Task 3: Developing new sub-models to update the GRASP model.

Task 4: Collating pasture growth and grazing trial data to provide a basis for land-type parameter sets and new model development.

Task 5: Analysing pasture growth and grazing trial data to test the model's capability and demonstrate new approaches to calculating pasture utilisation.

Task 6: The collation of land-type parameters and the creation of a library of parameter sets.

Task 7: Linking GRASP and the new CSIRO SE ENTERPRISE model that simulates the dynamics and cash flow.

Task 8 : Administering the project across the three collaborating organisations (QNR&W, CSIRO SE, QDPI&F) and liaising with other States and institutions.

Task 9: Communicating the project and the outputs through the GLM education package.

The GRASP modelling team was made up of many individuals who contributed enthusiastically to the completion of the project and were involved in many aspects of code and model development, the collection and analysis of pasture data, the development and running of the workshops, project administration and budget, managerial advice and support.

The project drew upon the support of other projects, especially AussieGRASS and SILO. In particular, the AussieGRASS team provided feedback on the operation of the code and model across Australia's grazing lands; and the SILO team provided reliable access to daily climate data (including a newly available synthetic pan estimate) fundamental to running GRASP at many locations.

The GRASP modelling team (in alphabetical order) included: David Ahrens, Andrew Ash, Ken Brook, Dorine Bruget, John Carter, Chris Chilcott, David Cobon, Robyn Cowley, Ken Day, Neil Flood, Grant Fraser, Beverley Henry, Greg Kociuba, Cam McDonald, John McIvor, Greg McKeon, Peter O'Reagain, Jo Owens, Andrej Panjkov, Col Paton, Mick Quirk, Joe Scanlan, Grant Stone, Peter Timmers, Brian Vandersee, Tracy Van Bruggen, Jackie Wakefield, and Giselle Whish.

Individual members of the team covered many roles. Key contributions of individuals are documented in the results and discussion (see section 4). In general terms, the responsibilities of the main contributors were:

Project management and reporting	Greg McKeon, Beverley Henry, Tracy Van Bruggen and Jackie Wakefield
Code development and testing	Neil Flood, Peter Timmers, John Carter, Grant Fraser and Jeff Clewett
Interface development and testing	Peter Timmers, Grant Fraser and Jeff Clewett
Model development and testing	John Carter, Grant Fraser, Jo Owens, Greg McKeon and Ken Day
Documentation, help notes and supporting information	Neil Flood, Peter Timmers, Grant Stone, Grant Fraser, David Owens and John Carter
Data organisation and analysis	Grant Stone, Grant Fraser, Greg McKeon and Ken Day
Collation of CSIRO SE grazing trial data	John McIvor, Cam McDonald and Andrew Ash
Workshop development, delivery and evaluation	Grant Stone, Peter Timmers, David Cobon, Joe Scanlan and Giselle Whish
Workshop presenters	Greg McKeon, Grant Stone, Peter Timmers, David Cobon, Grant Fraser, John Carter and Chris Chilcott
Guest workshop presenters	Ken Day, Jill Aisthorpe, Ron Hacker, Ian Watson, Robyn Cowley and Paul Novelly
Land-type parameters	Chris Chilcott, Giselle Whish and Ken Day
SILO climate data support	Greg Kociuba, Keith Moodie, Alan Beswick, David Rayner, Steve Jeffrey and Li Fitzmaurice
Project Steering Committee	Andrew Ash, Mick Quirk, Greg McKeon, Ken Brook, Brian Vandersee, Beverley Henry, Peter O'Reagain and Col Paton

3 Methodology

3.1 Task 1 – The development of new computer code and interface tools to use the GRASP model

The major task was to update the computer code of the model and develop a better modelling environment for scientists to simulate pasture production. The aim of this modelling environment is to provide a uniform capacity for scientists in northern Australia, and to facilitate training and future servicing of the model. Initial progress concentrated on in-house development for the eight scientists working in QNR&W on this activity. The principle was that if scientists within one group CINRS, QNR&W now QCCCE) have a uniform approach, and the same set of computing tools, then much greater testing and servicing of the model, and its working environment, would be achieved.

3.1.1 Towards better computer code

A major limitation recognised at the start of the project was that existing code versions of GRASP (Spaghetti, Surfair, WinGRASP, AussieGRASS) had diverged and that a new computer code base had to be established. It should be emphasised that this has not been a ‘mechanical’ task; it has involved an intense scientific review and new coding of sections of the model as necessary over the period of the project (2004 to 2007). The development of new sub-models and code is risky and a major allocation of project time has been committed to testing under operational conditions.

Over the period of the project, N. Flood developed a new set of (FORTRAN95) code (CedarGRASP) and supporting documentation that is both a repository of the last 30 years of progress and a base for future sub-model development. The FORTRAN code was implemented and checked in AussieGRASS by J. Carter, D. Bruget and P. Timmers. Sub-models were added by G. Fraser and J. Owens. New sub-models (described later) have been coded by N. Flood after consultation with QNR&W pasture scientists. A version control process was implemented to maintain code and facilitate clearer design of new developments.

3.1.2 Towards a better modelling environment

P. Timmers developed a new interface for the GRASP model called the GRASP Calibrator. This interface provided an improved modelling environment for using GRASP. Three major training workshops for 40 pasture scientists were conducted which provided a clear demonstration of the capability of the GRASP Calibrator. In addition, individual pasture scientists (G. Whish, R. Cowley) had one or two day working sessions with members of the GRASP modelling team to gain a more in depth understanding of the model.

The GRASP Calibrator was supported by the development of additional tools addressing the issues of managing climate data, observations from field trials and the calculation of field results collected using the SWIFTSYNpD methodology:

These tools were tested at the Katherine workshops (February 2007) and changes then made based on that experience. The interface and tools provide the basis for training in three major workshops.

3.2 Task 2 - Training of pasture scientists in the use of the interface and the model

As part of developing the training workshop program for pasture scientists, three of the project operatives (G. McKeon, G. Stone and P. Timmers) completed a Certificate IV Course in Training and Assessment in August 2006. The GRASP workshop training program was then designed to incorporate the training, evaluating and assessing procedures recommended in this course.

In terms of planning the training Workshops, the MLA Project Management Committee (M. Quirk, A. Ash and C. Chilcott) provided advice on the different levels of expertise that were expected to be achieved by participants. Seven levels of expertise were defined (see Section 4.2.1). These levels of expertise became part of the workshop evaluation.

An important part of training is the assessment of whether the participants actually learnt and acquired skills in the use of the model. At each of the three major GRASP workshops (‘Katherine’, ‘ARID’ and ‘Queensland’), an independent evaluation was carried out before and after the Workshop to assess the changes in participants’ understanding and capability in using GRASP Calibrator. This independent assessment was carried out by D. Cobon who had recently joined the GRASP Modelling Team and who had considerable experience in evaluating workshops (e.g. RAINMAN, DROUGHTPLAN) in terms of their capacity to increase understanding and knowledge.

3.3 Task 3 - Development of new sub-models to update the GRASP model

The explicit hypothesis underpinning GRASP is that a set of model parameters (e.g. available soil water range, potential nitrogen uptake, minimum nitrogen concentration for growth) can be derived from short-term field trial and then used to extrapolate across time, space and management options. The major limitations to this approach were reviewed at the start of the project and the recognised limitations include:

- Variable partitioning between roots and shoots, leaf and stem;
- Variable minimum nitrogen concentration for plant growth;
- Woody plant dynamics and tree micro-climate effects;
- Improved estimates of soil evaporation and tree/grass transpiration from deeper soil layers;
- Better parameterisation of deep soil layers especially the deep soil layer accessed only by trees;
- Runoff and soil loss sub-models for specific soil types;
- Changes in pasture composition especially between desirable and undesirable pasture species;
- Calculation of animal intake; and
- Liveweight gain and animal energy/protein balance.

The priority issues for the major applications (land-type pasture growth simulations and analysis of grazing trials) were: (1) alternative runoff models; (2) variable dilution of available nitrogen; and (3) calculation of animal intake and pasture utilisation.

The sub-models developed to achieve this task were:

- Multi-layer surface cover model;
- Rainfall intensity;
- Improved models of surface runoff, hydrology and soil erosion;
- Soil evaporation from deeper layers;
- Variable nitrogen dilution;
- Nitrogen in dry matter flow model;
- Tree micro-climate;
- Links to remote sensing data; and
- Management records and observations, and miscellaneous changes.

3.4 Task 4 – The collation of pasture growth and grazing trial data to provide a basis for land-type parameter sets and new model

To support the main applications (land-type pasture growth simulations and analysis of grazing trials), available pasture growth studies and grazing trials were reviewed and where possible data collated. The project also developed computing tools to facilitate creation of management record files.

The collation of pasture growth data across northern Australia that had commenced in earlier projects was continued. Studies that were collated included: M.J. Norman at Katherine in the 1960s; C.P. Miller at Meadowbank in north-east Queensland in the early 1970s; E.K. Christie at Charleville in the early 1970s; L. Cafe at Katherine in the late 1990s; M. Cobiac and R. Dyer in the Victoria River District in the mid-1990s; D. Orr in the Drought Recovery Project; J. Aisthorpe in support of GLM in Central Queensland.

An important issue for estimating potential nitrogen uptake was that the maximum nitrogen yield used in GRASP to parameterise a land-type occurs some time before peak dry matter yield, and hence delaying field sampling to capture peak autumn pasture yields is likely to result in underestimation of potential nitrogen uptake. Given the importance of the GRASP parameter *potential nitrogen uptake* in discriminating between land-types, an improved nitrogen flow sub-model was developed accounting for the above-mentioned issues. This will allow future interpretation of previous datasets collected.

A major task in the project was to collate historical grazing trials (CSIRO SE and QDPI&F) in a computerised form that could be added to the database of existing trials. To this end, CSIRO SE was subcontracted to prepare and make available files of important grazing trials.

3.5 Task 5 - The analysis of pasture growth and grazing trial data to test the model's capability and demonstrate new approaches to calculating pasture utilisation

The application of GRASP concentrated on several major datasets:

- Calculation of utilisation in the MLA funded Wambiana grazing trial (G. Stone and G. Fraser);
- Parameterisation of SWIFTSYNpD sites in the channel country of western Queensland (G. Fraser);
- Documentation of the impact of tree strips on pasture production in southern Queensland in the MLA Project NBP.316 Assessing the value of trees in sustainable grazing systems (G. McKeon and colleagues);
- Preliminary analysis of Glentulloch grazing trial in southern Queensland (G. Whish and QNR&W colleagues);
- Calibration of Northern Territory SWIFTSYNpD sites (≈25 sites, R. Cowley, the NT SWIFTSYNpD team, and the members of the GRASP modelling team);
- Calibration of Kimberley pasture yield time series at several sites (A. Craig and J. Scanlan).

3.6 Task 6 - The collation of land-type parameters and the creation of a library of parameter sets

A major application of the model as stated in objectives was to support the development and delivery of the GLM package. In GLM, C. Chilcott and colleagues used selected land-type parameters for the Burnett, Burdekin, Victoria River District, Mitchell Grasslands and Western Downs to provide simulations of pasture growth. Calibrated parameter sets derived in 1995 (DAQ124 RIRDC, Day *et al*. 1997) were used. The next stage was to update these parameterisations and to provide parameter sets for central Queensland (51 land-types or 40 central Queensland land resource areas, Maranoa/Balonne – 17 land-types and Northern Gulf land-types). A major challenge for the GRASP project was that the GLM delivery for central Queensland was due in May/June 2005 at the start of the project which preceded the completion of the major modelling development milestone (Milestone 7, February 2006). To address this issue, C. Chilcott and G. McKeon developed two procedures described later in Appendix 9.13.

Given the important regional differences in land-types and production systems, C. Chilcott and colleagues developed about 250 different land-type descriptions across 13 catchments or unique pastoral zones. Land-types were management units that displayed characteristic patterns of landform, soil and vegetation communities. Land-types were defined by pasture composition and growth characteristics; soil structure, fertility and texture; and tree species and density. Model parameters were derived from this information.

In GLM, simulated growth outputs were presented to land managers as pasture production tables for each land-type. The GLM the land-type pasture production information was used to calculate long-term livestock carrying capacity and for forage budgeting through an industry-based education workshop and use of associated decision support tools. An expected outcome of these tools is an increase in the uptake of management practices that improve animal productivity and land condition.

An important development in parallel with the GRASP modelling project has been the successful completion of a PhD Thesis by M. Cobiac (2007) 'Predicting Native Pasture Growth in the Victoria River District (VRD) of the Northern Territory'. The PhD was accepted on January 21 2007. In his Thesis (pp 254-255), M. Cobiac calibrated GRASP for 21 sites in the VRD region of the Northern Territory and described the limitations in estimating land-type parameters for GRASP where fertility limits pasture growth.

M. Cobiac (2007, page 56) made the following recommendations to improve the GRASP model:

Improvements to model structure

- Simulating separate biomass pools for perennial grasses and ephemeral species;
- Developing a dynamic model for year-to-year variation in nitrogen supply and dilution;
- Modifying the rainfall intensity and runoff components to simulate simultaneous wetting of the whole soil profile in cracking clays; and
- Incorporating a phosphorus index to better describe the effect of nutrient supply on pasture growth.

3.7 Task 7 – The link between GRASP and the new CSIRO SE ENTERPRISE model

The project objectives required GRASP to be developed in such a way that it could be linked to associated decision support packages. One such package is the herd dynamics/cash flow model (ENTERPRISE) developed by A. Ash, N. MacLeod, C. McDonald and colleagues. The ENTERPRISE model uses simulation output from GRASP with variables such as growth index days, utilisation, and liveweight gain as inputs to a herd dynamics model which calculates reproduction and mortality of the herd, and the financial consequences. At the start of the project, the ENTERPRISE model used output from the Spaghetti version of GRASP. The CEDAR version was developed to provide almost the same output variables and hence minimal changes should be required to update with a new version of GRASP when appropriate. This application of GRASP was previously documented by CSIRO SE (MacLeod and Ash 2001, MacLeod *et al.* 2004).

3.8 Task 8 – Project administration across the three collaborating organisations (QNR&W, CSIRO SE, QDPI&F) and liaison with other States and institutions

The project involved three Research an Development (R&D) agencies (QNR&W, QDPI&F and CSIRO SE). The individuals involved had cooperated previously on a basis of goodwill. The GRASP modelling project formalised this cooperation through a Memorandum of Understanding (with QDPI&F) and sub-contract (with CSIRO SE).

To aid project collaboration and communication, a Project Steering Committee was formed involving (a) senior managers of the three agencies and MLA (B. Vandersee, Director Resource Processes, QNR&W, M. Quirk, QDPI&F, A. Ash, CSIRO SE, K. Brook, Manager CINRS, QNR&W and J. Childs, MLA), and (b) two scientists involved in major applications, P. O'Reagain (Wambiana), C. Paton (GLM and MLA tree project). Thus the project had the support and evaluation of R&D managers as well as potential users.

One deficiency that needed to be addressed towards the end of the project was the involvement of Northern Territory and Western Australian scientists in the project. Through other projects (e.g. PaddockGRASP, Land Water and Wool and M. Cobiac's PhD thesis) liaison was also maintained with scientists in northern Australia and relevant rangeland areas, such as NSW and WA.

3.9 Task 9 – Communication of the project and the outputs through the grazing land management education package

The project was closely linked to the GLM education package through the involvement of M. Quirk and C. Chilcott. GLM was regarded as the principal avenue for communicating the outputs of the project (i.e. pasture growth tables) to producers. It was also envisaged that CSIRO SE would take the lead in terms of preparing publications describing applications. The description of the model and supporting documentation was handled by the QNR&W modelling team. The workshops were seen as a major form of communication to the pasture scientists learning the use of GRASP and understanding its outputs.

4 Results and discussion

4.1 The development of new computer code and interface tools to use the GRASP model

To achieve the primary objective of the project, the major goal was to develop a better modelling environment for scientists to simulate pasture production. This modelling environment was to provide a uniform capability to scientists in northern Australia and to facilitate training and future servicing of the model.

The goal of Task 1 was simply stated as:

> "a GRASP user should expect to be able to learn how skilled practitioners (e.g. K. Day or J. Carter) operate and to be able to be trained in those procedures so that they can operate confidently alone with a minimum of servicing".

A second goal was that:

> "model parameterisation should be reproducible and transparent and hence have a more scientific base than currently (2002) perceived (i.e. to make parameterisation more of a science than an art)".

Before the project, the modelling environment for GRASP was fragmented and represented the computing skill of individual practitioners at the time (i.e. skills developed from 1960s to 1990s). To provide a better modelling environment, the following steps were completed:

1) A modular design was developed to allow the different components of the modelling activity to be dealt with separately.
2) A new version of code (CEDAR) that can be updated easily by programmers adopting current standards.
3) A procedure for parameterisation of pasture growth studies in grazing trials that is reproducible and transparent.
4) Documentation of how to run the model as well as the underpinning biophysical science and the assumptions that have been made in developing the model.
5) A library of PowerPoint presentations (developed for the workshops) that will allow users to be informed on the different components of the modelling environment.
6) Training workshops and evaluation that ensures that users are comfortable in the application of the model.

4.1.1 Modular design

The overall modular design of the modelling environment is shown in Figure 4.1.1. Many of these procedures were lumped together in Spaghetti confusing the actual model with data analysis, output and applications. However the modular design now allows each component to be used independently.

One of the modules available allows for field data entry (e.g. SWIFTSYNpD studies) and the preparation of pasture growth studies and grazing trial data in a form (called .mrx files) that can be read by the model (.mrx is the file extension for management record files). These files also include parameters specific for the study being calibrated and simulated. This is important for the process of model parameter calibration which requires many iterations of the model comparing simulated with observed data. Other modules include the organisation of daily climate data especially the checking of daily rainfall. The project team found from experience that the most common source of problems is in the preparation of daily rainfall files and hence approaches were developed to better deal with the errors that occur in rainfall measurement.

Modules also relate to: (a) the organisation of parameters, (b) setting up control files to run the model, (c) the conduct of data analysis with calibration, and then (d) standard applications using the derived parameter set. The modular design will also allow users to conduct application simulations drawing upon established library parameter sets. Both model application and development of the modelling environment occurred in parallel and hence there was a continual re-evaluation of the modular design, this process will continue after project completion.

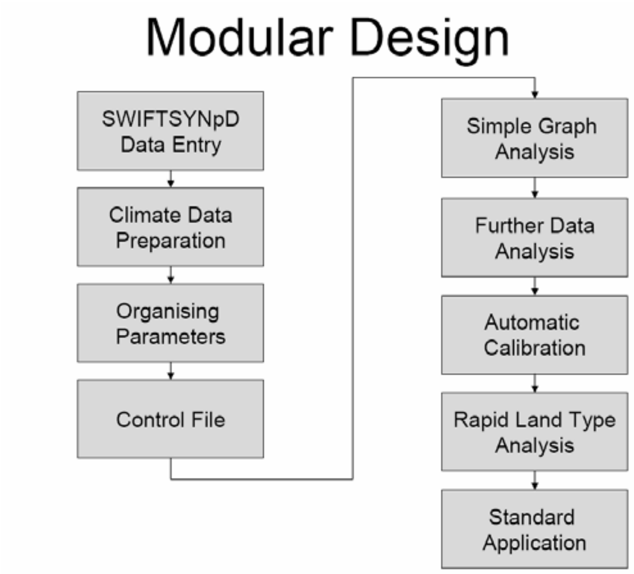


Figure 4.1.1: Modular design of the modelling environment for the use of the GRASP model showing the order in which the user might use the modules to conduct a study from entering measured data through to a standard application. Examples of standard applications are given in Section 1.1.3.

4.1.2 Code development

N. Flood (QNR&W) implemented an exemplary coding standard, which allows the FORTRAN95 code to be read by motivated users who have a moderate knowledge of computing. The project team have examples where users have been able to take the code and modify it for their own purposes (e.g. M. Stafford Smith in his analyses with HerdEcon, Stafford Smith *et al.* 2000). An example of the code is given in Table 4.1.1.

From the viewpoint of continuity in science of modelling, N. Flood's achievement in coding ensures that the computing component of GRASP model is not dependent on the continuing availability of the original developers such as G. McKeon, J. Carter and K. Day. Future modellers wishing to improve components of GRASP will find the code in a suitable starting point, providing continued investment from supporting organisations. A major achievement early in the project was the comparison of Spaghetti and CEDAR versions of GRASP and understanding the differences in simulation results.

Code development has also included modifying selected model functions to avoid sharp transitions or thresholds. For those readers with a detailed mathematical 'bent', this development is important for: comparing versions of the models given that numeric precision can cause 'semi chaotic' behaviour around these threshold points, and optimisation by gradient descent optimisation methods that require the model output to be continuously differentiable in respect to the inputs.

Table 4.1.1. An example of the new code in GRASP highlighting the calculation of potential growth from transpiration.

```
ratio%growth_ndx = ratio%temp_ndx * ratio%rad_ndx * ratio%total_grass_swi

!  Adjust transpiration-efficiency (TE) from standard 20mb to
!  actual vpd.
!  If vpd is less than 1, assume that it has no effect on TE

   vpd_sward = max(1.0, met%vpd * ratio%vpd_hgt_ndx)
   rate%TE = grass_P%TE_std * STD_VPD / vpd_sward

!  calculate grass foliage projective cover from green yield.
   ratio%rad_cover = 1.0 - exp((state%green_leaf + state%green_stem) *
   (-grass_P%yld_cover_slope / grass_P%yld_FPC50))

!  calculate potential growth from transpiration.
   rate%growth_trans = rate%TE * rate%trans_grass

!  Modify RUE for diffuse radiation
   RUE = modifyRUE(grass_P, met, options, ratio%RUEmod)

!  calculate potential growth from radiation, temperature and nitrogen.
   rate%absorbed_rad = met%rad * ratio%rad_cover
   rate%growth_rad = rate%absorbed_rad * RUE * min(ratio%temp_ndx, ratio%N_ndx)

!  potential growth from existing grass basal area
   rate%growth_regrow = grass_P%pot_regrow * state%grass_BA * ratio%N_ndx
   *     ratio%growth_ndx

!  Actual grass growth from the above potentials
   rate%growth_rad_trans_ltd = min(rate%growth_trans, rate%growth_rad)
   rate%grass_growth = max(rate%growth_regrow, rate%growth_rad_trans_ltd)
```

4.1.3 The GRASP Calibrator

To address the need for a uniform modelling environment, P. Timmers developed a 'front end' or user interface for GRASP called the GRASP Calibrator.

The GRASP Calibrator has the following capabilities:

- Capacity to easily run simulations for different land-types and climate stations;
- Graphical display of all variables simulated by the model including soil water, hydrological components, pasture growth and dry matter flow, nitrogen uptake and concentration, tree water use and other attributes, stocking rate and other grazing variables and aspects of degradation risk (utilisation and soil loss);
- Conditional probability analysis of simulated variables (e.g. especially pasture growth);
- Graphical comparison of observed and simulated variables particularly important for analysis of pasture growth and grazing trial data; and
- Growth analysis in which pasture growth is graphically compared to a range of variables such as simulated growth index that facilitates parameterisation.

This interface allows most of the tasks of user-implemented parameterisation, land-type selection and simulation to be easily performed. A key feature is that the user can more easily calibrate a parameter set (.mrx file) to fit observations. It does this by producing a series of preformatted graphs which are commonly used by expert calibrators. Graphs compare simulated output with observed data. A 'pasture growth analysis' is also conducted by presenting graphically a comparison of observed data with simulated components such as comparing standing dry matter yield with accumulated transpiration. This procedure allows some parameters to be directly derived from the pasture growth analysis. While the primary aim was to produce the graphs and hand the changing of parameters over to the user's favourite text editor, a simple front end to the common parameters has been added, which uses predefined parameter sets to adjust parameters representing a combination of land-type attributes. All changes made to a parameter set are retained and it is possible to go back through the run history to compare changes in how well the different simulations have compared to the observed data.

The GRASP Calibrator has the following detailed features as described below.

The first screen allows the user:

- To identify the parameter file, that contains the default parameter set and is aligned with a version of the model that they are running;
- To specify the .mrx file which contains the parameters that are likely to be changed for the particular site being calibrated as well as the management records and pasture/soil water observations collected at the site;
- To select the climate station containing daily climate data; and
- Options for carrying out parameter changes, growth simulation studies, analysis of observed growth data compared to simulation outputs, historical long-term simulations and construction of pasture growth tables suitable for GLM.

Depending on the option selected, a range of other screens are available that allow the user to:

- Carry out a detailed land-type analysis by changing soil water and pasture growth parameters; and
- Plot all possible variables in the grazing system that are simulated in GRASP.

The breakthrough in GRASP Calibrator is that it has overcome the limitations of previous versions of GRASP in terms of comparing observed and simulated values, as well as being able to examine and modify all variables that are in the GRASP model. As the name of the interface suggests, GRASP Calibrator is an excellent tool for first-time users to run the model, examine output and compare with field data.

The ease with which the GRASP Calibrator can be used was demonstrated at the Katherine Workshop (February 2007) by the rapidity with which pasture scientists who had not previously been exposed to the GRASP model, were able to change parameters, run simulations, and produce pasture growth tables. Similarly, pasture scientists were able to carry out initial calibration procedures using their own data within the GRASP Calibrator environment.

The GRASP Calibrator is supported by the following tools:

- *P51 merge*: which allows site rainfall to be included in a daily climate file derived from SILO;
- *Management record merger:* which allows the different records collected in carrying out a pasture growth study or a grazing trial to be merged in a form suitable for creating a .mrx file that can be run with the GRASP Calibrator; and
- *SWIFTSYNpD template sheets:* which allows the entry of field data for the calculation of soil water and pasture growth data.

These tools were tested leading up to the Katherine Workshop (February 2007) and changes continue to be made based on current use.

The GRASP Calibrator covers several of the modular components including organising parameters, simple graph analysis, rapid land-type analysis, and climate risk assessment applications.

Although the GRASP Calibrator provides most of the capability needed by users, those users who wish to carry out their own plotting and analyses are still able to access all of the necessary files within the CEDAR output files.

4.1.4 Additional parameterisation and calibration tools

Calibration of model parameters from field data is a major task in running the model. The procedure allows a series of parameters to be manually calibrated with previous calibration examples readily displayed (Figure 4.1.2). In the past those scientists conducting calibration had to develop their own graphical procedures. The GRASP Calibrator, for the first time, provides a standard capability and hence forms the basis of training users in the procedures of dealing with model parameterisation.

A number of simple tools have been developed to explore the relationship between a given set of field measurements and a given set of parameters believed to influence the modelling of that dataset. These relationships can be very complex and attempts to estimate parameters from field data without understanding the nature of the particular relationship to the parameters can result in parameters with limited general applicability. The more the project team can learn about this relationship, for a given dataset, the better. Computing tools were also developed for understanding which parameters are of greatest importance in modelling a given set of field measurements. These tools also evaluated to what extent there are non-unique solutions in finding parameter values that minimise the difference between observed and simulated values.

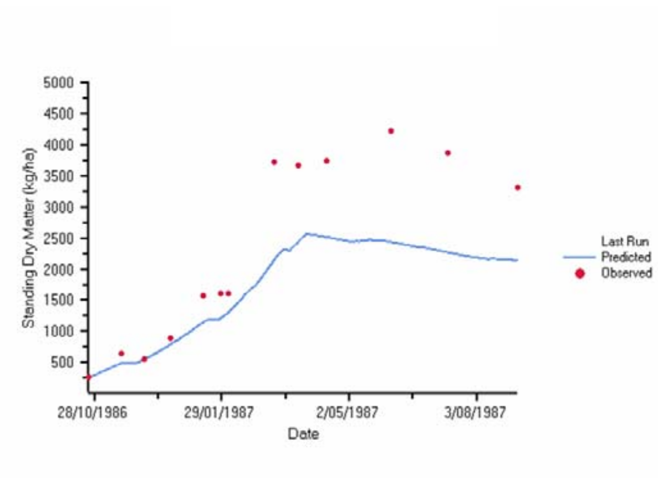
A tool has been developed implementing the Differential Evolution algorithm for parameter estimation. This is a multi-dimensional optimisation technique akin to genetic algorithms. Initial tests show that it is well able to take a soil water dataset and estimate soil water capacity parameters, but it remains to be seen how effective it will be in estimating other parameters from more complex sets of field measurements.

There is usually insufficient field data for complete parameterisation of individual sites and paddocks. As a consequence approaches are being developed to address the issues of independent validation and how to minimise the number of parameters required for calibration.

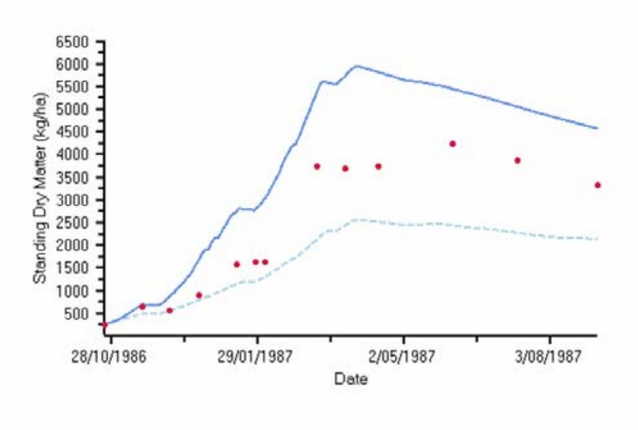
4.1.5 Documentation of model equations

In 1995, M. Littleboy wrote a detailed manual of GRASP (Littleboy and McKeon 1997) and this has been subsequently updated in NBP.338 to describe both the science and the limitations of the GRASP manual. The updated manual is still in ‘draft form’ in the sense that it is being continually updated. Thus, the manual provides users with an up-to-date description of the GRASP model. This is an important process in GRASP model development as there is likely to be an ‘explosion’ in demand for improved modelling components (see Section 7).

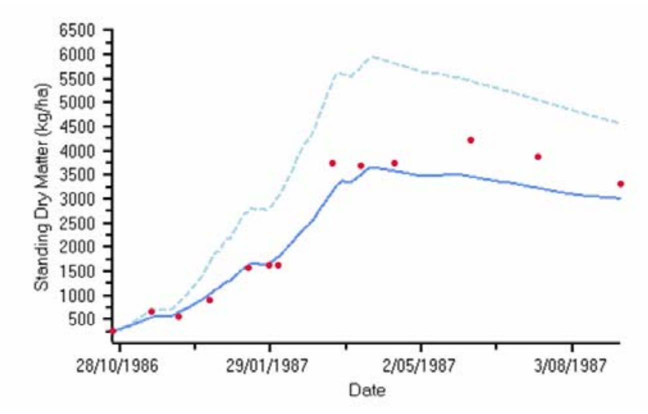
Examples of the information that is available from the manual documentation and other sources is given in Figure 4.1.3. The manual includes segments of computer code that can be read by users who have some programming training. The data supporting the relationships are also available as figures. In the example given (Figure 4.1.3), a component of growth is calculated from transpiration and an example screen from the GRASP Calibrator, allowing estimates of transpiration efficiency, is also shown. Thus, the manual and the GRASP Calibrator are designed to support each other.



a)



b)



c)

Figure 4.1.2. Example of model parameterisation using the GRASP Calibrator. The examples show how simple user-implemented changes to the parameter, transpiration use efficiency, can result in a better explanation of observed pasture data collected using the GUNSYNpD methodology (McKeon *et al.* 1990).

3.1 Water limited growth

Under water limited conditions, pasture growth can be represented by the product of transpiration efficiency and calculated transpiration. The daily growth limited by transpiration is:

$$growth\_trans = TE \,.\, trans\_grass \qquad \textbf{[3.1]}$$

where

growth_trans	potential growth from transpiration (kg ha^{-1} day^{-1})
TE	transpiration efficiency (kg ha^{-1} mm^{-1})
trans_grass	daily plant transpiration (mm) (from equation 2.22)

Transpiration efficiency is the amount of above-ground biomass produced for every mm of transpiration. It is adjusted from the standard 20 hPa to the actual daily vapour pressure deficit.

Figure 4.1.3a. An example of documentation and supporting data for the relationship being discussed. The code segment shows how one component of growth is calculated as the multiplication of transpiration efficiency and GRASP transpiration.

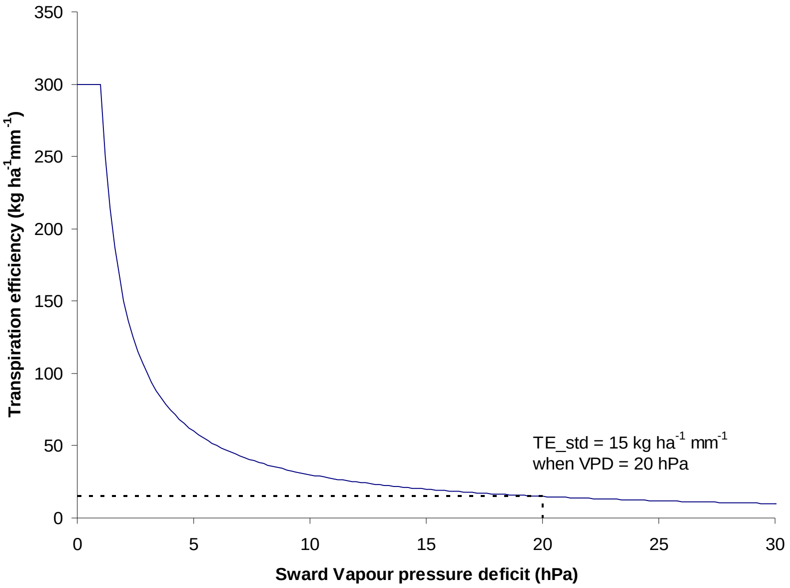


Figure 4.1.3b. Example of manual documentation - the relationship between transpiration efficiency and vapour pressure deficit used in the model is similar to that proposed by Tanner and Sinclair (1973).

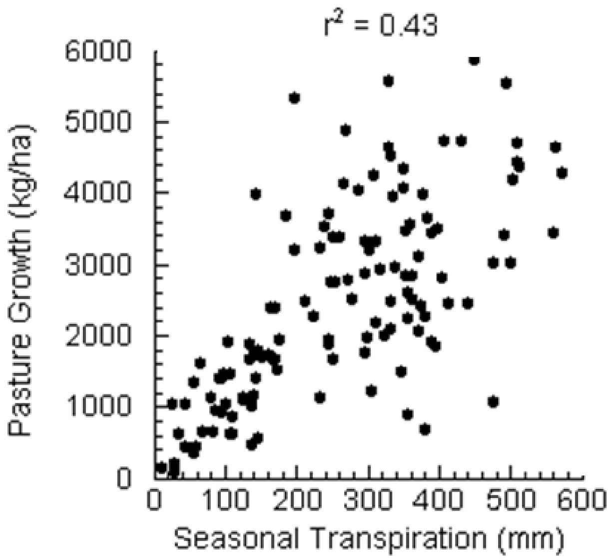


Figure 4.1.3c. Example of manual documentation - Seasonal transpiration accounts for a high proportion of pasture growth, especially when water availability is limiting over the growing season (<200mm).

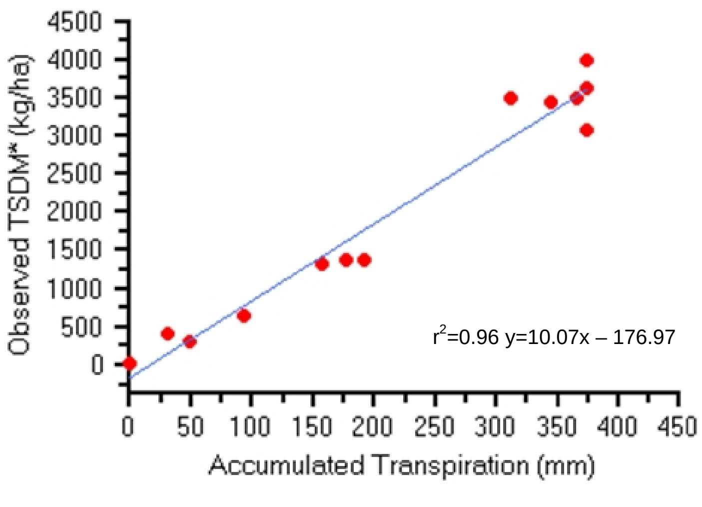


Figure 4.1.3d. Example of manual documentation - Transpiration efficiency can be calibrated for individual sites, e.g. Figure 4.1.2.

4.1.6 Code and operational documentation

N. Flood has documented carefully the components of running CedarGRASP including: (a) a general introduction describing the philosophy of coding; (b) how control files operate; (c) examples to get started; (d) the names of variables to obtain any output; (e) how to run the model; (f) a description of the parameter files; (g) the links between parameter numbers and Cedar variables for

Spaghetti users; (h) how to run groups of simulation experiments called ‘stacks’; (i) how to run multiple jobs with varying parameters; (j) how to access the source code; (k) a description of the development history; and (l) a procedure for testing agreement between Spaghetti and Cedar.

4.2 Training pasture scientists

Objective 2 of the project was to train more than 12 officers to be able to use GRASP, parameterise the model, run simulation studies, analyse grazing trial data and develop materials for GLM and decision support packages.

To achieve this objective, the project components were: (1) training of trainers; (2) design of workshops in consultation with prospective participants; (3) testing of materials; (4) delivery of training in safe learning environment; and (5) evaluation of the workshops.

Three major 3-day workshops were run in 2007 with 40 pasture scientists participating (e.g. Plates 4.2.1 and 4.2.2). The results of the workshop evaluation are discussed in Section 4.2.3.

Plate 4.2.1. Examples of workshop delivery and participation for the major workshops. A range of learning styles were catered for in the workshops, including hands-on simulation, presentations from invited speakers, structured learning exercises allowing users to 'walk through' prepared demonstrations at participants'/users' own pace, and round-table discussions providing the opportunity for user feedback following participatory exercises.

Plate 4.2.2. The second GRASP modelling workshop held at Natural Resource Sciences centre (NRSc) Indooroopilly (May 2007) for participants from Arid regions (western Qld, WA and western NSW). Paul Lawrence (QCCCE Acting Manager) welcomed participants and described the current and future relevance of modelling for the sustainability of the natural resource base, the grazing industry, lease renewal and land condition, and the over-arching issue of climate change.

4.2.1 Levels of expertise

In planning the training Workshops, the MLA Project Management Committee (M. Quirk, A. Ash and C. Chilcott) provided advice on the different levels of expertise that were expected to be achieved by participants. Seven levels of expertise were defined. Table 4.2.1 provides a brief description of the capability and knowledge was required at each level. An important point that was made at the Katherine Workshop was that the capability of carrying out the SWIFTSYNpD trial was an important part of the expertise involved in modelling. The success of the Katherine Workshop was, in part, due to the fact that many of the participants (NT pasture scientists) had actually carried out several SWIFTSYNpD trials and hence, were receptive to the use of the model in terms of representing and simulating their own data. As a consequence, the ability to carry out a SWIFTSYNpD trial was formally included in the two levels of expertise (Levels 1 and 5).

Table 4.2.1. Levels of expertise in the use of GRASP

	Capability	Skills and Knowledge Required
Level 1	Carry out a SWIFTSYNpD trial Understanding of biophysical components of pasture growth	Knowledge of components of the grazing system and how to make measurements of soil moisture, pasture yield and cover, nitrogen analyses and detail site descriptions
Level 2	Confidence in model outputs Understanding of model capability	Real world knowledge of grazing systems and biophysical processes Model definition and boundaries Caveats on the use of the model
Level 3	Run Land-type option Change parameters	Components of land resources e.g. soils, depth, texture, hydrology, soil fertility, pasture composition, growth form Understanding of parameters
Level 4	Run DOS, cedar.exe Develop control files Able to input simulation results into own spreadsheet	Use of spreadsheets Use of CoPlot (or other plotting software) Simulation experiment capability
Level 5	Collect and enter own data Calibrate Use output in report Run and interpret the simulation	Field data collection/analysis Text Editor for changing parameter files Understanding error messages and warnings Ability to carry out a SWIFTSYNpD trial
Level 6	Run factorial and optimisation tools Write a report and a critique using simulation results	Sensitivity of model to parameters Critical faculty for recognising implausible simulations
Level 7	Write a new sub model and parameterise Carry out systems analysis Use GRASP as a sub routine	Model development Systems analysis procedures Programming skills

4.2.2 Workshop development and preparation

Consultation

For the Katherine workshop, the managers (R. Cowley and P. Novelly) of pasture science groups from the Northern Territory and Western Australian government agencies were consulted to ensure that objectives/aims of the planned workshops reflected the needs and existing experience of participants. Subsequent workshops were built on this design with appropriate refinements. C. Chilcott, manager of pasture scientists in QDPI&F was also a workshop presenter and was able to indicate what type of presentations would meet his groups' needs.

In preparation for the Workshop, participants were also consulted on their experience and expectations. The main conclusion from the review of experience and expectations was that whilst there was good knowledge of the grazing industry, there was some apprehension in terms of the use of computer modelling packages, and hence the training workshops were designed to reduce this anxiety. Feedback indicated that the workshops were successful in this regard, due mainly to the user friendliness and clarity of the GRASP Calibrator interface developed by P. Timmers.

In running the workshop, the project team used the knowledge gained in the Certificate IV Course in Training and Assessment to cater for the different learning styles (e.g. activist, pragmatist, theorist, reflector) of participants. For example, the project team recognised that the activists needed to ‘get up and running quickly’; the pragmatists wanted to know about practical use the model; the theorists wanted to know what the biophysical processes were in the model; and the reflectors wanted to know how accurate the model was when compared to field data. The project team found this a useful way in presenting the workshops to cater for different learning styles simultaneously in the presentation of the potentially complex material that spans simulation modelling, grazing system understanding and systems analysis, sophisticated computing tools, and the detailed knowledge associated with land-type parameters.

The presentations and training were supported by a wide range of materials and documentation, (see Appendix 9.6). Various demonstrations allowed the participant to follow step-by-step the procedure to carry out a simulation (Demonstration 1 in Appendix 9.6). Feedback from some of the workshop participants indicated that more structured activity examples would be useful; and more demonstrations were developed for later workshops.

4.2.3 Evaluation of workshops

An important part of training is assessing whether the participants actually learnt and acquired skills in the use of the model. In the case of the three-day workshops, an independent evaluation was carried out before and after the workshops to assess changes in understanding and capability in using GRASP Calibrator based on self assessment (Table 4.2.2). This independent assessment was carried out by D. Cobon who had recently joined the GRASP Modelling Team and had considerable experience in evaluating workshops (e.g. RAINMAN, DROUGHTPLAN) in terms of their capacity to increase understanding and knowledge. These evaluations (given in Appendices 9.2, 9.3, 9.4 and 9.5) indicated a substantial increase the level of expertise in terms of the different tasks or levels involved in using GRASP (Table 4.2.3). The evaluation carried out by D. Cobon provides useful information on what level of expertise participants are likely to reach. The project team knew from experience that the highest level of expertise in using the GRASP model (level 7) requires years of commitment and experience, possibly supported by post-graduate study.

For each level of expertise (Table 4.2.1) there were a series of tasks that were assessed (Table 4.2.3). For example, level 2 required the capability of producing GRASP outputs, understanding the input parameters and knowledge of the files used in GRASP. Level 3 required an understanding of the land-type options in GRASP, how to carry out a seasonal analysis and how to use the GRASP Calibrator in analysing field data.

Overall assessment of the 40 participants was as follows:

- The 40 participants had a total of approximately 595 years (range 0 months to 50 years) associated with the beef industry and 313 years (range 0 months to 30 years) with modelling;

- 14 participants (35%) attained a working knowledge of all GRASP tasks indicative of level 3 expertise;
- 22 participants (55%) attained a working knowledge of 2/3 GRASP tasks indicative of level 3 expertise;
- 5 participants attained a working knowledge of all GRASP tasks indicative of level 4 expertise;
- 5 participants attained a working knowledge of all GRASP tasks indicative of level 5 expertise;
- 4 participants attained a working knowledge of all GRASP tasks indicative of level 6 expertise; and
- 3 participants attained a working knowledge of all GRASP tasks indicative of level 7 expertise.

Table 4.2.2. Self assessment scale used in workshop evaluation

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
No Knowledge		Some Knowledge		Average Knowledge		Working Knowledge			Superior Knowledge

Key to knowledge ratings:
No: No understanding of the term at all
Some: Heard of the term, some idea what it means but not confident to use it
Average: Reasonably confident understand the term and can apply it
Working*:* Confident understand the term and can apply it
Superior: Expert understanding and knowledge of the term and have applied

Table 4.2.3. Average score of 40 workshop participants, before and after the workshop (WS) for various GRASP tasks associated with different levels of expertise

GRASP task	Level of expertise	Pre WS	Post WS	Significance level #
SWIFTSYNpD	1	4.2	6.9	P<0.01
Grasp outputs	2	4.5	6.7	P<0.01
Grasp parameters	2	3.8	6.4	P<0.01
Grasp files (eg. mrx, p51, prv)	2	3.1	6.4	P<0.01
Land-type options in Grasp	3	3.0	6.5	P<0.01
Seasonal analysis	3	3.5	6.4	P<0.01
Calibrator	3	2.2	6.5	P<0.01
Cedar	4	2.4	5.4	P<0.01
Control of output (control files)	4	2.2	4.8	P<0.01
Grasp data entry	5	2.6	5.6	P<0.01
Grasp calibration	5	2.6	5.9	P<0.01
Grasp simulation	5	3.1	6.1	P<0.01
Error detection in Grasp output	5	2.1	4.8	P<0.01
Grasp sensitivity to parameters	6	2.4	5.2	P<0.01
Grasp factorials/stacks/optimisation	6	1.7	4.4	P<0.01
Develop a new Grasp sub-model	7	1.7	3.2	P<0.01

Paired t test

Evaluation by science managers

Both R. Cowley (Rangeland Program Coordinator, Pastoral Production, Northern Territory Department of Primary Industry, Fisheries and Mines) and P. Novelly (Manager, Rangeland Research, Western Australia Department of Agriculture and Fisheries) provided verbal evaluation indicating that they thought the workshop was successful in meeting the expectations of their teams. Further evaluation following the follow-up workshop in the subsequent week is documented in Section 4.2.4.

R. Hacker (NSW DPI) provided the following comment:

> Dear Greg, Just a note to thank you, and all others concerned, for organising what was an excellent workshop. I believe it, and others in the series, will prove to be a significant milestone in the development of modelling capability in the Australian rangelands. The advent of the GRASP Calibrator has put very significant capacity at the disposal of the rangelands science community nationally and I believe will be the stimulus for a significant and coordinated approach to the application of modelling to the issues of sustainable rangeland use in an era of declining physical resources. Of course it will be vital for your group to continue as the coordinating focus for this effort and I look forward to continued cooperation.

Ian Watson (WADA&F) provided the following comment:

> Greg, just a short note to thank you and your team for running the recent (May 07) GRASP Calibrator workshop for the southern rangelands.
>
> It was extremely well run and you had obviously put a lot of work into organising it. One thing you deserve extra brownie points was for the way you catered to a wide range of pre-existing knowledge and a range of needs amongst the participants, giving that some of us had already had some exposure to GRASP while others had previously had no exposure. Plus you quite explicitly catered for the different learning styles amongst the participants which I found a nice touch.
>
> Obviously, one reason for the workshop's success was that GRASP Calibrator is now a fantastically useful piece of software. It is relatively easy to use but without losing any of the sophistication that is needed. P. Timmers has obviously put a lot of work into achieving those twin aims.
>
> Suggestions for improvement? At the workshop I made some suggestions to you about re-ordering the delivery of the various subjects covered - but having said that I also recognise that some participants want to get into the nitty gritty of the model, others want to see the biology behind it and others just want to get stuck into playing with their own data so I guess whatever order you decide to run with will never suit all participants. Some follow-up workshops would be good with those who really want to use GRASP in their day to day work or have a specific project in mind that they need help with.
>
> As a final observation, I am always impressed by your group's willingness to be non-parochial and to help us struggling in other states with our own issues. It is truly nice to see the Australia-wide approach to using GRASP and my guess is that while it may give you more work at the moment, our successors will be grateful that we have a national framework for modelling pasture growth that has been developed and nurtured in a spirit of co-operation rather than being imposed upon us simply because it is bigger and better. We all live on the same continent and your ability to both draw information and knowledge from outside Qld as well as disseminate Qld expertise back to us is outstanding.

Katherine workshop

The three-day workshop at Katherine (February 2007) was attended by 14 pasture scientists from the Northern Territory and northern Western Australia. The workshop concentrated on components of the model relevant to northern Australia where nutrients are more likely to limit pasture growth than rainfall. In these regions of northern Australia, there is also a low density of stations reporting rainfall. As a consequence, the lack of high quality rainfall data limits pasture growth simulation capacity. To overcome this deficiency, the SILO database has been developed to provide estimates of daily climate data for regions with sparse rainfall reporting. Thus, the workshop also included training in accessing the SILO database to run the GRASP model.

The self assessment of Katherine Workshop participants (Appendix 9.2) indicated that whilst there was a general working knowledge of 'beef or natural systems', there was less understanding of the biophysical processes which are fundamental to understanding GRASP and grazing systems. This self assessment approach, concentrating on 'working knowledge', provides an important benchmark to compare the levels of expertise achieved in the training workshop. For example, 25% of participants to this workshop reported that they achieved a 'working knowledge' on the five major tasks presented in the 3-day workshop (GRASP parameters, GRASP files, land-type options, seasonal pasture growth analysis and use of Calibrator). The other aspects of GRASP were presented to provide general overall understanding/awareness and hence a 'working knowledge' was not expected.

Arid GRASP workshop

The results of the workshop are presented in Appendix 9.3. Twelve participants attended the workshop from Gatton, Trangie, Longreach, Mt. Isa, Rockhampton, Brisbane, Karratha, Meekatharra and Northam. Between them they had a total of approximately 126 years (range 0 months to 39 years) associated with the beef industry and 110 years (range 0-30 years) with modelling.

Thus, the workshop not only provided training in the use of GRASP for scientists with similar modelling issues, but also represented an initial step towards developing a multi-state network of GRASP users across semi-arid regions. The workshop participants included D. Orr and D. Phelps, who had contributed substantially to model development through making their field data available (grass basal cover from grazing trials and in particular, the Toorak grazing trial).

Overall, the participants assessed their knowledge of beef and natural resource systems as 'average' to 'working' (6.0 out of 10) and an 'average' knowledge of biophysical processes (5.9 out of 10).

The 'average' knowledge of biophysical processes increased only slightly (not significantly) from the beginning of the workshop (5.9) compared to the end (7.2) ($P>0.05$, paired t test). There was also no change in the average knowledge of beef or natural resource systems during the workshop (Figure 1).

Pre-workshop the average knowledge of GRASP tasks was 3.0 indicating the participants had some knowledge, and post-workshop the average knowledge was 5.9 indicating the participants felt they had average knowledge. This difference between the average scores pre and post workshop was significant ($P<0.01$) using a paired t-test.

The knowledge of each individual task increased during the workshop. Of the 16 tasks evaluated, 12 tasks scored an average to working knowledge where these tasks were associated with the lower to middle levels of GRASP expertise.

Queensland GRASP workshop

The results of the workshop are presented in Appendix 9.4. Fourteen participants attended the workshop from a wide range of locations in Queensland (Gatton, Toowoomba, Brisbane, Rockhampton, Emerald, Dalby, Kairi, Yeerongpilly, Bundaberg and Roma). Between them they had a total of approximately 323 years (range 0 months to 50 years) associated with the beef industry and 158 years (range 0 months to 30 years) with modelling.

On average the participants had working knowledge of either beef or natural resource systems (7.3 out of 10) and an average to working knowledge of biophysical processes (6.6 out of 10).

The knowledge of biophysical processes was not different from the beginning of the workshop (6.6) compared to the end (7.1) ($P>0.05$, paired t test). There was also no change in the average knowledge of beef or natural resource systems during the workshop.

This workshop included participants who had contributed to model development through the collection of field data and/or were applying the simulation results in GLM. Thus, the workshop participants had the knowledge background to support the use of simulations from GRASP.

Pre-workshop the average knowledge of GRASP tasks was 3.2 indicating the participants had some knowledge, and post-workshop the average knowledge was 6.3 indicating the participants felt they had an average to working knowledge. This difference between the average scores pre and post workshop was significant ($P<0.01$) using a paired t-test.

The knowledge of each individual task increased during the workshop. Of the 16 tasks evaluated, 15 tasks scored an average to working knowledge where these tasks were associated with the lower to middle levels of GRASP expertise.

4.2.4 Katherine workshop on SWIFTSYND calibration, documentation of an objective calibration procedure

In the follow-up Workshop at Katherine (25 February to 1 March 2007) which concentrated on calibration, J. Scanlan led the training in calibration procedure whilst G. Fraser, G. McKeon and G. Stone collated the SWIFTSYNpD data from over 25 sites in a form that could be used with GRASP. Participants were then able to see how their data could be put into .mrx files as well as repeat the calibration procedure for their own sites. A. Craig (WADAF) also had time series of pasture standing dry matter involving documented burning events and hence these data were also suitable for calibrating pasture growth parameters. He was able to follow the procedure in which these data could be put into suitable .mrx files with observations of burning dates as well as observed pasture yields. A. Craig and M. Jeffery evaluated the model in terms of meeting the needs of the GLM packages developed for the Kimberley Region of WA. In consultation with J. Scanlan, A. Craig was able to calibrate parameters using these datasets and this analysis will be available for future GLM simulations.

A brief review of what was achieved in the workshop by the pasture scientists (known as SWIFTSYNpDers) has been provided by R. Cowley:

- All SWIFTSYNpDers reviewed steps in calibration and practiced calibrating SWIFTSYNpD sites using one of C. Smith's sites;
- All SWIFTSYNpD site data entered and SWIFTSYNpDers 'walked through' a calibration of a couple of their own sites;
- All SWIFTSYNpDers were able to read and edit an 'mrx' file manually;
- List of things to do in calibration was developed;
- Draft calibrations for some SWIFTSYNpD sites were carried and will be finalised when remaining data are available (bulk density, nutrient analysis, additional SWIFTSYNpD harvest data and any MINISYNpD harvests)
- Discussed ideal SWIFTSYNpD sampling time for different regions and parameter values (referred to in calibration documented were discussed);
- SWIFTSYNpDers identified gaps in current datasets to target for future sampling – e.g. at field capacity, soil moisture at reset, peak N, N samples to be ground, future MINISYNpDs where peak N had been missed or for different seasonal conditions if both SWIFTSYNpD years similar; and
- List of the problems in measuring rainfall were discussed.

As a result of the activities at the follow-up Katherine workshop which concentrated on calibration, R. Cowley and J. Scanlan have refined the rules of calibration (Appendix 9.14). This was a very important step in achieving the objectives of the MLA project as it indicates that two people outside the main model developers and calibrators could derive and test an objective procedure, and thus, develop a more reproducible and transparent approach to model calibration. This achieved one of the intentions of the MLA project (4.1), in that a legacy of modelling expertise now exists independently of the original model developers (G. McKeon, K. Day and J. Carter).

4.2.5 Conclusion

Objective 2 of the project was successfully achieved. However, a major learning from this activity was the need for:

- Ongoing renewal of the skills involved in this complex task;
- Ongoing improvement in the computing tools and the model to address emerging issues;
- Service capacity to deal with the coming 'explosion' in demand to service data collation and calibration; and
- More training workshops to build user capacity.

Successful progress has been achieved in the task of training pasture scientists. Nevertheless, further workshops will be conducted in 2008 to ensure that the progress from initial training is not lost. These workshops will concentrate on model calibration, briefing managers, landscape sustainability and climate change.

It was particularly encouraging that the NT SWIFTSYNpD team (led by R. Cowley) had demonstrated a capacity to carry out detailed field studies on over 25 sites providing the necessary information to derive parameters for simulating pasture growth. This expertise so well demonstrated by the NT team indicated that capability, pasture modelling and supporting field data collection exists more widely than just in Queensland. Given the interest also shown in WA (P. Novelly), MLA should consider how it might further support this emerging network of pasture scientists involved in systems analysis and grazing system modelling.

4.3 The development of new sub-models to update the GRASP model

4.3.1 Need and priority for new sub-models

The explicit hypothesis underpinning GRASP is that a set of model parameters (e.g. available soil water range, potential nitrogen uptake, minimum % nitrogen for growth) can be derived from short-term field data and then be used to extrapolate across time, space and management options.

The deficiencies in GRASP have been well documented in various reviews conducted since 1995 (Dyer *et al*. 2001, Richards *et al*. 2001, Tupper *et al.* 2001, Day *et al*. 1997, McKeon *et al.* 1998, various AussieGRASS reports). A list of these known deficiencies and limitations is given in Table 4.3.1.

Table 4.3.1. List of known limitations in GRASP from previous reviews and review of other models (Richards *et al*. 2001 and Tupper *et al*. 2001).

GRASP: Limitations

- accounts for only 60-70% of variation in pasture standing dry matter
- no species components only sward simulated
- no plant phenology nor leaf/stem sub-model
- lack of species composition change
- lack of forb component in perennial grasslands
- no roots or variable root/shoot ratio through growing season
- detachment and decomposition processes not well understood
- no explicit consumption by insects and other herbivores
- no phosphorus or potassium effects on plant growth
- most problems at ‘wet end’ where nitrogen dilution is most important
- need to complete carbon/nitrogen cycles
- tree micro-climate effects on pasture production not tested

GRASP: Soil water balance limitations

- difference between saturation and field capacity not resolved for many soils
- point on landscape and hence no lateral flow
- run-off does not become run-on and hence run-on sites not simulated
- tree cover not dynamic hence may over-estimate winter/dry season tree transpiration
- tree water use too sensitive to daily variation in pan
- no tree interception layer for rainfall
- no impeded or lateral drainage
- validation of water balance only with soil water measurements
- ‘layer 4’ available water (> 100cm) can not be measured at most locations

GRASP: Advantages of other models not included in GRASP

- SEESAW (western NSW)
  – ‘plant functional types’ with parameters and phenology
  – seed dynamics
  – sheep and wool production at seasonal time scale

- nitrogen flow in dry matter
- landscape processes

- ARIDGROW (central Australia)
  - evapo-transpiration linked to soil characteristics
  - detachment of ephemerals
  - lumped daily rainfall (2-3 day events)
- IMAGES (southern rangelands, WA)
  - shrub dynamics as well as ephemerals
  - long time step (4 months) for shrubs
- GRASSGRO (high rainfall zone of southern Australia)
  - more sophisticated water balance especially at 'wet end'
  - infiltration attributes and bulk density used as inputs
  - theoretically sound in terms of physics and physiology
  - nitrogen and phosphorus sub-models available
  - individual species parameterisation

Modelling effects of increasing grazing utilisation: sub-models required in GRASP

- change in soil attributes affecting runoff
- surface cover varies with species composition
- more leaf and less stem
- more nutrients required to grow dry matter
- plants more prostrate
- less roots
- more sensitive to water stress
- less nutrient uptake
- replacement with earlier flowering species or unpalatable species, e.g. *Aristida*
- woody plant increase

Where to invest in GRASP model improvement for rangelands modelling?

- dynamic nitrogen uptake/dilution
- runoff models for land-types
- dynamic trees/shrubs
- browse availability
- carbon/nitrogen flow
- soil erosion (wind and water)
- grazing feedbacks on productivity
- detachment/decomposition process
- species composition change
- phosphorus

GRASP has been developed incrementally since the late 1970s concentrating on the simulation of pasture growth. The major limitations that have been identified over the last 30 years (since 1978) are:

- Cover, runoff and soil loss sub-models for specific soil types;
- Variable partitioning between roots and shoots, leaf and stem;
- Calculation of animal intake;
- Improved estimates of soil evaporation and tree/grass transpiration from deeper soil layers;
- Changes in pasture composition especially between desirable and undesirable pasture species;
- Woody plant dynamics and tree micro-climate;
- Better parameterisation of deep soil layers especially the deep soil layer accessed only by trees;
- Liveweight gain and animal energy/protein balance; and
- Variable minimum nitrogen concentration for plant growth.

From consideration of the main applications, priority was given to areas most relevant to land-types simulating runoff models, and the analysis of pasture growth and grazing trials (minimum nitrogen and changing parameters).

After review of a large number of potential animal intake models (Section 4.5.1), it was decided that the calculation of pasture utilisation at this time (2008) was best carried out outside the GRASP modelling environment. This procedure is described in more detail in Section 4.5.

The application of GRASP to the wide range of land-types and communities in northern Australia was required to support the use of pasture growth tables in this area. Model development and parameterisation to address knowledge limitations was outside the bounds of the project, however, there was a need to develop sub-models that would allow scientists to analyse pasture and hydrological datasets and create parameter sets for future use in the GRASP environment. The development of these new sub-models is briefly described below, with more detailed explanation provided in Appendix 9.7 and 9.8.

However, it is recognised that in developing new sub-models, great care is required. The project team have found that there is little point in adding ‘functionality’ (i.e. new sub-routines) if they cannot be parameterised and tested across the wide range of land-types in northern Australia. Creating extra parameters that need to be estimated also reduces the practicality of the use of the model in achieving relatively simple goals. Based on a mid-project review, a qualitative evaluation was carried out on which sub-models to develop. This evaluation was based on a consideration of both feasibility and importance to the objectives of pasture growth simulation. A further consideration was whether the new sub-model would have strong feedbacks to the overall performance of the simulation of pasture growth (e.g. a new minimum nitrogen concentration sub-model), or whether the new processes being modelled provided only additional information on the response of the grazing system to management (e.g. soil erosion sub-model).

4.3.2 Development of better hydrological models

The development of better runoff models for different land-types required better sub-models of surface cover, rainfall intensity and impermeable soils. These developments are described in greater detail in Appendix 9.7.

1) Multi-layer cover model

A multi-layered cover model accounting for the different contributions of pasture standing dry matter, pasture litter and tree litter has been developed by J. Carter. This new cover model is necessary to drive the new runoff models that are being developed for different land-types as these models are parameterised using all cover components (i.e. including pasture and tree litter).

As part of development of the new cover model, the consumption of litter by animals was also considered. A better estimate of cover will allow comparison with new data sources available from remote sensing such as bare ground index.

2) Rainfall intensity

A new rainfall intensity model calculating rainfall intensity from daily climate data has been developed. Unlike cropping situations where the soil surface is regularly disturbed, runoff from pasture soils is thought to be particularly sensitive to rainfall intensity. This is because of the low rates of infiltration associated with many grazing situations. However, rainfall intensity is not a standard climate variable available spatially or historically. As a consequence, there has been a need to develop better estimates of rainfall intensity from daily climate data. G. Fraser and J. Carter have developed a new sub-routine which is now available in CEDAR GRASP, allowing for rainfall intensity to be addressed. The sub-routine has been developed on data from the ‘Top End’ of the Northern Territory to Tasmania, and hence has wide application for northern Australia. The intellectual property of subroutine is part of G. Fraser’s PhD Thesis, which is sponsored by MLA.

3) General runoff model for grazed pastures

Grazed pastures differ substantially from cropping soils, particularly in surface characteristics such as surface sealing, impermeable sub-soil and in some cases, shallow soil depths. As part of his MLA funded PhD project, G. Fraser has developed a more general form of runoff model as a function of cover, rainfall intensity and a soil cover response factor (SCR). The SCR has been derived for a range of soils and land-types. It could provide a more general approach to deal with the wide range of land-types and rainfall intensities that occur across northern Australia. Appendix 9.7 describes the application of the approach to the different soil types used to develop the Scanlan equations used in GRASP. Appendix 9.7 also describes the development of a sub-model to explicitly simulate runoff from soils with impermeable layers at depths such as duplex soils. These sub-model developments provide a base for a more comprehensive coverage of land-types in northern Australia.

4) Duplex soil runoff model

A runoff sub-model for duplex soils accounting for soils with restricted infiltration capacity at depth has been developed. Some land-types in the grazing lands (duplex soils) have restricted infiltration, and as a consequence general runoff calculations underestimate runoff, especially under high surface cover. G. Fraser has developed a ‘duplex-overflow’ sub-model in CEDAR GRASP which is now being tested.

5) New version of Scanlan runoff model

The original runoff model in GRASP (coded in 1991) represents the preliminary analysis of the data from Charters Towers. Subsequently, a re-evaluation of the data was made as reported in Scanlan *et al.* (1996). This later form of the model has also been included by G. Fraser as a sub-model.

Similarly, the calculation of soil loss was developed from the data presented in Scanlan and McIvor (1993). The sub-models calculating soil loss are being updated (April 2008) to include subsequent analysis (after Scanlan *et al.* 1996).

4.3.3 Varying minimum percent nitrogen for plant growth and potential nitrogen uptake

A major application of GRASP is the simulation of pasture growth using 100 years of climate data. This output is used in climate risk assessment, for example, calculating probabilities for ENSO phases. For land-types with low fertility or locations with high rainfall with low year-to-year variability, simulated pasture growth is dominated by two parameters: *potential nitrogen uptake*; and *minimum nitrogen concentration*. These parameters are held constant from year-to-year and hence little year-to-year variation in pasture growth is simulated. Short-term field studies suggest that greater year-to-year variation in observed pasture yields occurs compared to growth simulated by GRASP under these conditions (i.e. fertility limiting growth).

To address this issue, a review (Appendix 9.8) was conducted of GUNSYNpD and SWIFTSYNpD pasture growth studies to re-evaluate how the pasture attributes (peak nitrogen yield and minimum nitrogen concentration) vary from year-to-year. The review reports the difficulty of developing a general understanding from short-term (2-3 years) studies with low frequency of sampling (e.g. 1-2 sampling measurements). Nevertheless some hypotheses consistent with general spatial and temporal observations were developed and have been coded as new sub-models. The review suggested that minimum nitrogen concentration was the most important source of variation. A new sub-model calculating the parameter *minimum nitrogen concentration* as a function of the vapour pressure deficit and/or diffuse radiation was coded. Parameterisation for different species and land-types is yet to occur, but with the development of a GRASP Calibrator, parameterisation of individual sites can now occur.

An initial test of the likely improvement resulting from varying the parameter *minimum nitrogen concentration* was carried out using the 100 pasture growth studies collated by Day *et al.* (1997). The studies had been individually manually calibrated and involved 983 observations of pasture standing dry matter. Overall, the manually calibrated root mean square (RMS) was 599 kg/ha with calibrated *potential nitrogen uptake* varying considerably between sites (0.3 to 1.1%N). From these studies, an average native pasture parameter set was subjectively derived (McKeon *et al.* 1998). The average value for *potential nitrogen uptake* was estimated at 0.68%N (weighted across Queensland's pasture communities) and when used for the 100 studies, resulted in an RMS of 672 kg/ha.

The lowest RMS found for a constant *potential nitrogen uptake* across all studies (0.55%N) was 620 kg/ha. The lower value of *potential nitrogen uptake* (0.55 compared to 0.68%N) reflects the generally lower values of *potential nitrogen uptake* found in the 'black spear grass' and *Aristida Bothriochloa* pasture communities. When *potential nitrogen uptake* was simulated daily for either low or high % diffuse radiation conditions (threshold 30% diffuse), then the RMS was 600 kg/ha very similar to the RMS values (599) when each site was manually calibrated. The overall R^2 value (for 983 observations) was lower (0.795) than the overall individually calibrated site R^2 value (0.824), suggesting that some improvement could be made by including individual site (species) characteristics. For example, sites dominated by forest bluegrass (*B. bladhii*) had a lower minimum nitrogen concentration (0.3%N) than other sites (average native pasture value of 0.68%N). Similarly, black spear grass and *Aristida/Bothriochloa* pasture communities had lower average values (0.40 and 0.41% respectively). The next step is to use CedarGRASP and the capability for automatic calibration to develop new relationships. As in other examples of adding new sub-models, some recalibration of existing parameters will be required.

Nitrogen in dry matter flow model

An important sub-model development identified in GRASP has been the capability of carrying out a flow of nitrogen (uptake and removal) in pasture standing dry matter. Work on this sub-model had stopped because of the difficulties of parameterising processes such as translocation of nitrogen at the end of the growing season. However, with the advent of the GRASP Calibrator and the extensive datasets from SWIFTSYNpD trials from the Northern Territory, a better simulation of these complex processes can now be made and parameters developed. This will improve the capability of GRASP to simulate pasture growth in nutrient limiting situations. Over 1720 measurements of sward nitrogen concentration (164 from MODIS MLA project) have been incorporated by J. Carter into the AussieGRASS calibration structure to provide a meta-analysis for model development. The close relationship between the AussieGRASS and the GRASP modelling projects has provided a capability to rapidly test developments across a very wide range of soil, vegetation and climate environments. The testing of GRASP in AussieGRASS, with meta-datasets (i.e. data from across Australia) has provided additional information to the parameterisation of GRASP from individual pasture growth sites and grazing trials.

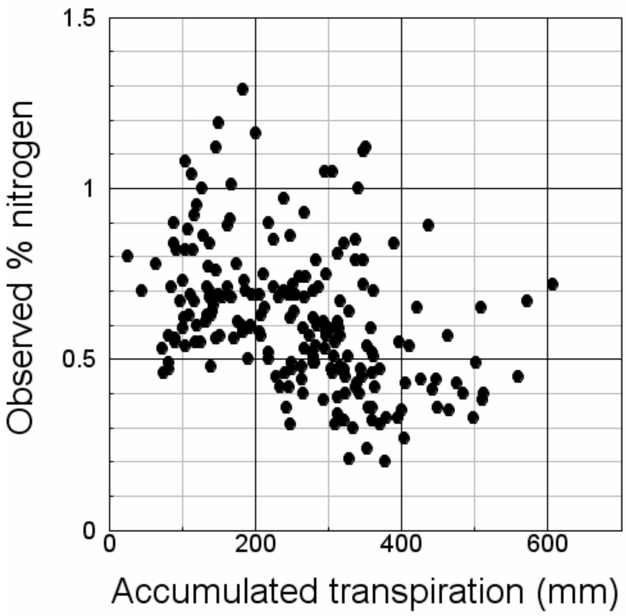


Figure 4.3.1. The relationship between observed percent nitrogen in standing dry matter and accumulated transpiration since the start of the growing season**.** The data are from the GUNSYNpD/SWIFTSYNpD data set of 100 pasture growth studies. Values are for the months of March, April and May and for standing dry matter >1000 kg/ha.

Radiation use efficiency and diffuse solar radiation

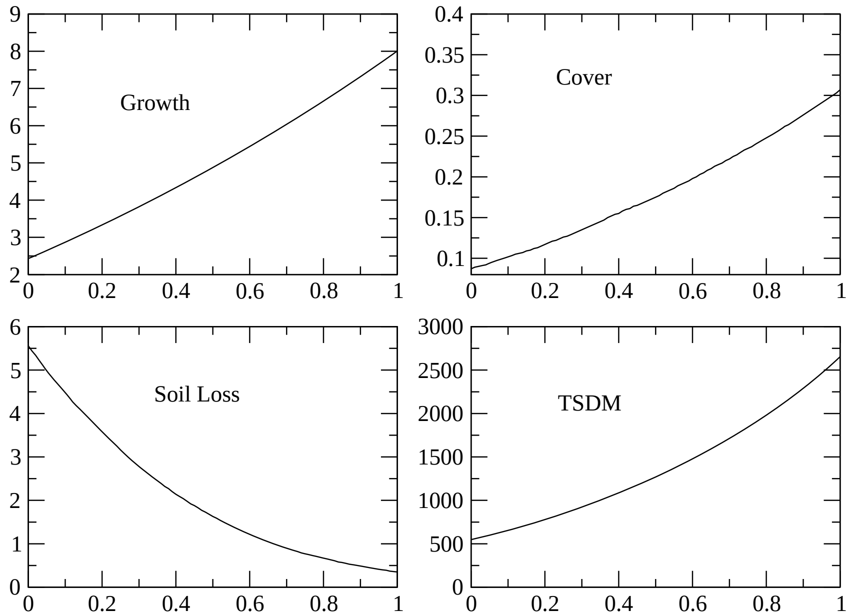
J. Carter has continued to develop the radiation use efficiency component of the model with particular attention to the impacts of diffuse radiation. This area of model development was identified as an important prerequisite to the development of the sub-model varying minimum nitrogen concentration, particularly in coastal and northern Queensland and 'Top End' of the Northern Territory. Re-evaluation of previous experimental work suggested that large increase in radiation use efficiency can occur in tropical grasses under shading. This component of the model also provided some understanding of the possible impacts of tree strips documented in the MLA project NBP.316 Assessing the Value of Trees in Sustainable Grazing Systems (Chilcott *et al.* 2008).

4.3.4 Simulation of botanical composition change and blended parameter sets

The explicit hypothesis underpinning GRASP is that a set of model parameters (e.g. available soil water range, potential nitrogen uptake) can be derived from short-term (one or two years) field data and then used to extrapolate across time, space and management options. Monocultures such as black speargrass with annual burning, and naturalised or aged sown pastures dominated by buffel grass will provide a test of this assumption. However, a general feature of native pasture swards is the number of pasture species and ecotypes that vary in their year-to-year contribution to pasture growth. A major limitation in GRASP, that has always been explicit, is the inability to change parameters as a result of changes in botanical composition. A first approach to overcoming this limitation was developed in McKeon *et al.* (2000) using the changing composition model developed by Ash *et al.* (1996). In the approach described in McKeon *et al.* (2000), a selected number of parameters were changed each year in response to an index of species composition (percent desired perennials). A sub-model was included in GRASP which allowed the botanical composition to be changed in response to dry matter utilisation over the preceding 12 months. This approach was effective in simulating both perennials and annuals and the swings in composition between these two vegetation states.

In the current GRASP modelling project, N. Flood developed a more general approach to the modelling of changes in parameters. Parameters for two states are specified (State 1 and State 2) and a procedure is used to calculate at a specified time interval a 'blended' parameter set. This approach provides a very flexible way of dealing with a range of issues such as change in parameters due to: Carbon dioxide increase; changes in botanical composition; woody component decrease or increase; climate impacts; and pasture/land degradation and recovery resulting from interaction of climate and grazing pressure. Thus this approach will provide the ability to handle a limited set (i.e. two) of state and simple transitions between states (e.g. climate and/or grazing effects). However, a general State and Transition model is yet to be formulated and was outside the scope of this project.

To test the effect of 'blending' parameters, attributes of the grazing system were simulated for varying proportions of two parameter sets representing two vegetation states. The parameter set for State 1 was the average native pasture parameter set commonly used for simulation studies. State 2 was a composite of parameters representing degraded vegetation with mainly annual species. The parameters in State 2 include higher minimum percent nitrogen required for plant growth, greater sensitivity to soil moisture stress and reduced nitrogen uptake. Figure 4.3.2 shows the simulation of some grazing systems attributes (growth, cover, total standing dry matter, and soil loss) for an unburnt grazed native pasture with different proportion of States 1 and 2. The curvilinear relationships with proportion of State 1 are in contrast to the expected linear relationships that would be calculated if independent simulations were conducted with State 1 and State 2 and then the simulation results calculated based on the proportion of each State. Thus the 'blending' of parameters provides a powerful approach of representing how parameters change at a sward or plot level but does not provide the same simulation result where States 1 and 2 are spatially separated (e.g. as could occur at a paddock or greater scale).



Proportion of State 1 Parameters

Figure 4.3.2. Simulation of attributes of the grazing system for varying proportions of two parameter sets**.** The parameter set for State 1 was the average native pasture parameter set commonly used for simulation studies and now used as a base for parameterising new sites. State 2 was a composite of parameters representing a degraded vegetation with mainly annual species. The attributes of the grazing system are (1) pasture growth (kg/ha/day), (2) pasture cover (proportion), (3) soil loss (kg/ha/day), and (4) total standing dry matter (TSDM kg/ha).

4.3.5 Tree effects on pasture micro-climate

An important feature of northern Australian native pastures is the presence of trees at varying densities. The competitive effects of trees are simulated in GRASP by tree water use and nitrogen uptake. However, the beneficial effects of trees on understorey micro-climate have not been previously included in the application version of GRASP. Following the work of G. Dupont and J. Carter (Dupont *et al.* 1996, Dupont 1997) in southern Queensland, equations were coded to simulate the effect of tree density (expressed as Foliage Projected Cover, FPC) on the pasture microclimate maximum and minimum temperature, solar radiation and vapour pressure deficit. The sub-model also includes the effect of FPC on rainfall interception. Thus, the sub-model provides a capability to investigate the beneficial as well as competitive effects of trees (Figure 4.3.3). The beneficial effects of trees, especially at low tree densities, are still being investigated. Particular attention is being paid to the effects of tree density on potential evaporative demand and diffuse radiation effects on pasture radiation use efficiency.

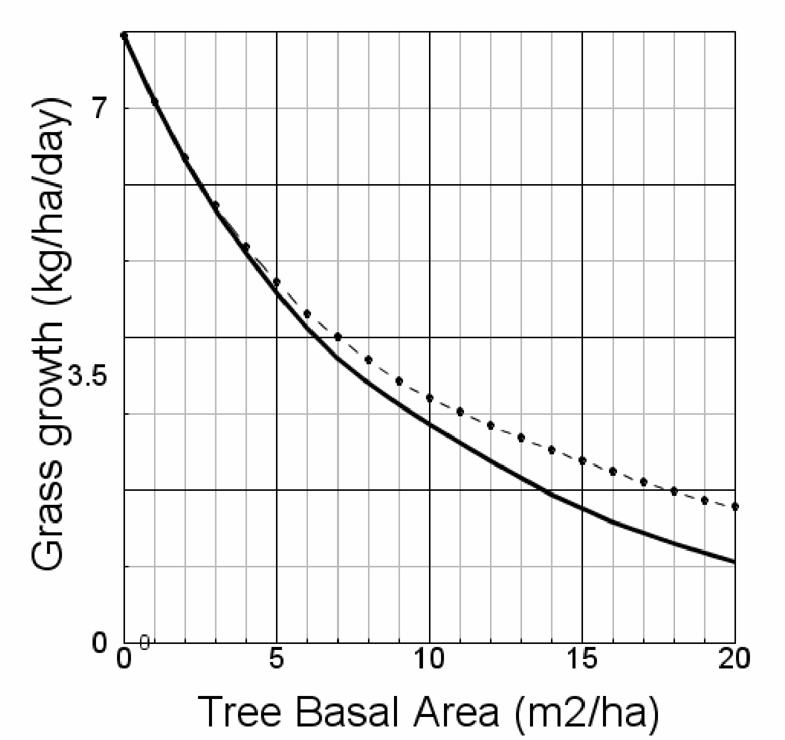


Figure 4.3.3. The effect of tree microclimate relationships on the simulation of pasture growth.

Miscellaneous changes

A large number of small but important changes have been made as part of a continuing review of each sub-routine in the model. For example, the management record subroutines have been brought up-to-date to include new types of observations, and equations to predict MODIS and LANDSAT derived NDVI have been implemented.

Equations defining the relationship between green cover and NDVI as measured by Landsat TM or MODIS satellites developed in MLA funded project NBP.330 Evaluation of MODIS for groundcover and biomass/feed availability estimates in tropical savanna systems are being prepared for inclusion in CedarGRASP. This will potentially allow the use of satellite data in future model parameterisation.

4.3.6 Conclusion

Whilst the objective of the project was not explicitly to build a better model, nevertheless the above improvements were regarded as necessary to meet the major applications of land-type simulations and the training of pasture scientists. Testing of these new components will continue in the future to assess ease of parameterisation and applicability across northern Australia.

4.4 The collation of pasture growth and grazing trial data to provide a basis for land-type parameter sets and new model development

An important task during the project was to continue the collation of new and historical pasture growth and grazing trial data sets (4.4.1). Given the limited time available only a limited number of these sets were parameterised as part of the project (4.4.2).

4.4.1 Review and collation of available datasets

An objective of the project is to develop a parameter library for pasture communities and land-types in northern Australia. This task involved the collation and analysis of both existing and new pasture growth studies as well as existing and new grazing trial data. A summary of these data sources is given in Table 4.4.1.

Table 4.4.1. Potential data sources for library of land-type parameters.

- Pasture Growth Field Studies
  - Existing 100 GUNSYNpD/SWIFTSYNpD studies
  - Top End Northern Territory studies (M. Cobiac, R. Dyer, L. Cafe, R. Cowley and NT SWIFTSYNpDers)
  - Central Queensland (Aisthorpe 31 sites)
  - Drought recovery project (Orr 6 sites)
  - Wambiana (O'Reagain 7 sites)
  - Natural Resources and Mines, Climate Impacts and Natural Resource Systems: Texas & Brian Pastures
- Grazing Trials
  - Existing studies: 5 sheep trials (Arabella, Burenda, Eastwood, Gilruth Plains, Toorak), P55 Brian Pastures (3 stages), Brigalow, Kangaroo Hills, Ladies Mile (Queensland)
  - Galloway Plains, Keilambete, Glen Tulloch, Toorak, Swans Lagoon, PDS, Manbulloo, ECOSSAT, Narayan, GLASS, Wambiana, Virginia Park (Queensland)
  - Mount Sanford, Pidgen Hole (Northern Territory)

There were several issues in terms of the analyses of these data sets. Not all data sets contain all the information necessary to parameterise the biophysical attributes of particular sites. In addition, grazing trials are conducted at a paddock scale which cover a range of different soil/vegetation units.

Some examples of data collation during the project are as follows:

1) G. Stone has completed the Galloway Plains data set involving the period from 1988 to 2001 with data from 28 individual paddocks being collated involving 4,400 individual management and observation records. Much of the preparation of data sets occurred prior to the project, however, this project is now using the collation to evaluate utilisation and botanical composition change models. In the project, the following grazing trials and field studies have been organised in standard data base form for use in GRASP: Wambiana, SWIFTSYNpD, Drought Recovery, J. Aisthorpe's 31 sites, and native pasture control paddock from Manbulloo.

2) J. Aisthorpe and colleagues have collected pasture production data at 31 sites in central Queensland involving three field samplings in the season of 2003/04. A new minimalist field procedure was used, called ‘MINISYNpD’, and had the aim of minimising the amount of field work to allow the coverage of a larger number of sites. QNR&W project team members (G. Stone, G. Fraser and C. Trevor) also participated in the end of season pasture sampling thus linking the modelling team with potential users in the field. J. Aisthorpe’s sites also include pasture production from sites with different age since tree clearing and hence provide a unique opportunity to address the issue of nitrogen rundown following clearing.

3) K. Day and colleagues have been continuing to sample the GUNSYNpD sites at Brian Pastures Research Station mostly set up in October 1986. These data represent the longest available time series of pasture production data available to the project (Appendix 9.15). They highlight that pasture composition changes when a constant management regime is imposed (in this case annual burning). Re-examination of the data collected in the early period when harvesting occurred at three weekly intervals has highlighted the deficiency of estimating peak nitrogen yield from a single harvest at the end of the growing season. As a consequence a different procedure will be drawn up for those scientists wishing to more accurately measure biophysical parameters for particular land-types.

The pasture growth data collected by K. Day and colleagues at Brian Pastures Research Station (Gayndah, South-east Queensland) provides an independent test of GRASP’s capability to simulate pasture growth. Soil and pasture parameters were derived for several sites from data collected from 1986/87 to 1992/93 (Day *et al.* 1997). Simulations were compared with data collected subsequently (1993/94 to 2003/04) and indicated that end of growing season standing dry matter was generally over-estimated, although the rankings of years and sites were maintained (Figure 4.4.1). The overall over-estimate of pasture growth could be due to several reasons, including:

1) Parameter bias derived from the individual calibration years such as 1989/90;
2) Changes in pasture composition and nutrient (e.g. nitrogen) availability due to regular annual burning of the exclosures; and
3) Climate ‘changes’ to a less humid/cloudy environment (Appendix 9.8).

Analysis of the measured data is still at a preliminary stage, and further interpretation will occur in subsequent years. Nevertheless, the study highlights the importance of developing long-term time series of pasture growth measurements, particularly with current and projected changes in climate likely to be affecting pasture growth.

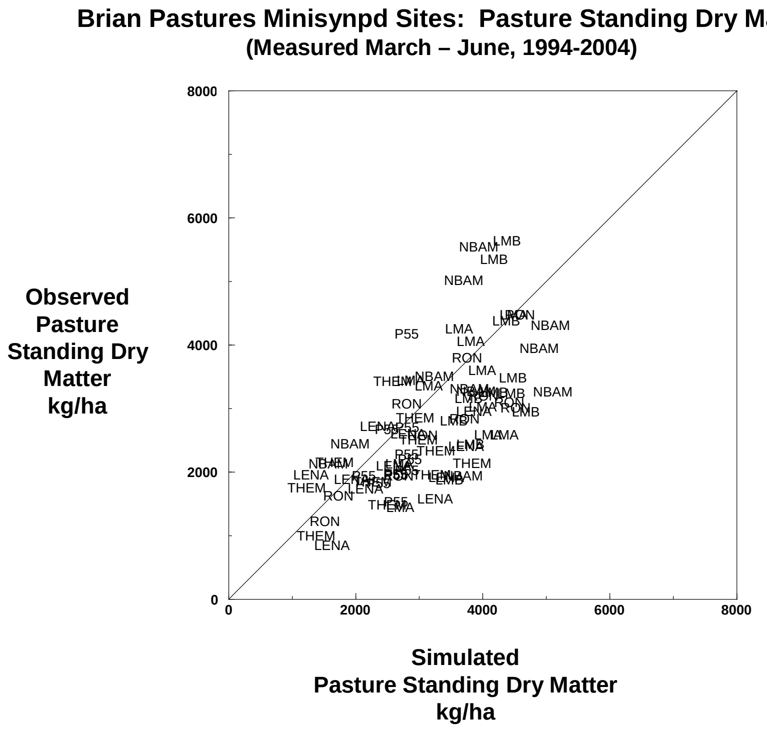


Figure 4.4.1. Comparison of simulated and observed pasture growth at 7 exclosure sites at Brian Pastures, Gayndah. The parameters for GRASP were derived from data collected from 1986/87 to 1992/93 (Day *et al.* 1997). The measurements were taken at the end of each growing season from 1993/94 to 2003/04 (11 years). The sites are: stony prarie soil on andesite (LMA, LMB, THEM); black earth on basalt (RON and NBAM); linear gilgai clay on andesite (P55); and coarse sand on granite (LENA).

Importance of measuring nitrogen yield in pastures

It is regrettable that the most important measurement that determines productivity of different land-types, *potential nitrogen uptake,* has not been commonly measured in historical pasture growth and grazing trial studies. Thus a major limitation to developing a library parameter set of pasture communities and land-types has been the lack of this information. The existing GUNSYNpD and current SWIFTSYNpD studies at least provide an approach to overcome this data deficiency.

The CSIRO SE grazing trials (Table 4.4.2) in the future will provide an opportunity to address the issue of how to model nitrogen impacts on pasture growth and year-to-year variability in nitrogen availability. For example, the Manbulloo trial (Katherine, NT) includes a native pasture treatment with regular burning and hence provides a time series of pasture yields in an environment where the major limitation is nitrogen availability. The CSIRO SE grazing trial E116 conducted at Narayen (Mundubbera, Queensland) was used by P. Filet in his PhD thesis. In this thesis, P. Filet (1988) provided a comprehensive analysis of the nitrogen cycle components for both native pastures and a Siratro-based pasture. Similarly the PhD thesis of G. Robbins (1984) includes information on nitrogen effects on pasture growth of a sown pasture species as well as the effects of changing nitrogen availability ('run down'). These trials and data should greatly increase the capability to model nitrogen limitations on plant growth.

Table 4.4.2. CSIRO SE Grazing trials that could be parameterised with GRASP.

- Manbulloo, near Katherine, Northern Territory: Grazed native pasture with burning, 20 years data of pasture (composition, growth, standing dry matter) and liveweight gain data.
- Glenwood, south east Queensland: GLASS trial using grazed native pasture data, 6 years of pasture (composition, standing dry matter) and liveweight gain data on different land-types
- Narayen, near Mundubbera, south east Qld: J. Tothill native pasture study with grazing of native pasture in eucalypt woodland, 10 years of pasture (composition, standing dry matter) and liveweight gain data
- Cardigan and Hillgrove, near Charters Towers, Queensland: ECOSSAT and ECOGRAZE grazed open eucalypt woodland, 18 years of pasture data (composition, standing dry matter, some growth studies)

For this project, CSIRO SE has collated the data from three major grazing trials (Table 4.4.2). As part of the project, the following reports and datasets have been prepared by J. McIvor:

- Pasture yields, botanical composition, liveweight gains and weather data at the CSIRO SE experimental site, Manbulloo, Northern Territory.
- Pasture yields, botanical composition, weather data and liveweight gains at the CSIRO SE experimental site, Glenwood, south-east Queensland.
- Pasture yields, botanical composition and weather data from the CSIRO ECOSSAT sites near Charters Towers, north-east Queensland.

However, the analysis of these trials is outside the scope of the project objectives.

4.4.2 Analysis of pasture growth studies and grazing trials with GRASP

The number of pasture growth data sets available was expanded from 100 to 162 during the project by incorporation of historical pasture growth data from:

1) Western Queensland (E.K. Christie's Mulga, Mitchell and Buffel grass sites);
2) Northern Territory pasture growth data collected by L. Cafe, R. Dyer, and M. Cobiac at Katherine, Kidman Springs and other locations in the Victoria River District;
3) Detailed studies at Katherine (M.J.T. Norman, 1963); and
4) Meadowbank and other sites in northern Queensland (K. Shaw, C.P. Miller).

These datasets have proved important, not only expanding the library parameter set, but also in developing the minimum nitrogen concentration sub-model (Section 4.3.3).

The application of GRASP during the project concentrated on several major datasets. The grazing trials are referred to in Section 4.8. The following parameterisation studies have been conducted and the pasture scientists carrying out the model parameterisation are indicated below:

- SWIFTSYNpD sites in the Wambiana grazing trial (NBP.318) in north-eastern Queensland, (G. Fraser and K. Day);
- Channel Country pastures, (NBP.329) in western Queensland (G. Fraser and K. Day);
- The impact of tree strips on pasture production in southern Queensland as documented in the MLA Project NBP.316 Assessing the value of trees in sustainable grazing systems (G. McKeon and colleagues);
- Glentulloch grazing trial in southern Queensland (G. Whish and QNR&W colleagues and independently J. Clewett);
- Northern Territory SWIFTSYNpD sites (≈25) (R. Cowley, J. Scanlan and the Northern Territory SWIFTSYNpD team); and
- Kimberley pasture yield time series at several sites (A. Craig and J. Scanlan).

The analysis of these different datasets continues to indicate GRASP has the capability to be parameterised to a wide range of the land-types and climate that occur in northern Australia. As a consequence of these studies, changes have been made to the model, as well as more objective calibration procedures have been developed. The result of GRASP's use in analysis of these datasets will be documented in the reports associated with the datasets.

4.4.3 Example of use of GRASP Calibrator for parameterisation

The application of GRASP to Channel Country pastures (Phelps *et al.* from NBP.329 Sustainable Grazing in Channel Country Floodplains) represented a major test for the model and the new modelling environment in that it involved:

1) Annual vegetation communities substantially different to perennial tropical native pasture;
2) Soils derived from alluvial deposition and inundated for long periods; and
3) Field data that contained substantial inter-quadrat variability.

The parameterisation of the sites was conducted by G. Fraser under the initial guidance of K. Day. G. Fraser was developing his experience in the use of GRASP and associated tools, and he brought his understanding of soils to the issue of parameterising plant available water range and soil evaporation in these 'difficult' soils (including possible chemical limitation to plant growth). Successful parameterisation was achieved once sampling variation in the field data was analysed allowing better estimates of plot yields as well as better estimates of deep soil water profiles. As part of the study, the model was improved based on G. Fraser's findings to include better approaches to calculating soil evaporation.

The success in parameterising these sites demonstrated that:

1) The skills of parameterising could be learnt by young scientists with a sound background in field studies and who then contributed to further model development;
2) The GRASP Calibrator provided an suitable tool to facilitate calibration;
3) The difficulty in initial parameterisation led to re-evaluation of field pasture data and better estimates of plot yield from photos;

4) The successful application of GRASP to unique pasture and soil land-types; and
5) Modelling of plant available soil range indicated likely chemical limitations to plant growth and water use.

Figure 4.4.1 shows the observed (point data) and GRASP simulated pasture yields for the Channel Country floodplains site on Glengyle (western Queensland). The components (including pasture and soil parameters) that were found to be important when calibrating the channel country floodplain sites were: the flood inundation and recession dates; the soil water holding capacities which were quite variable between sites; and the species regrowth rates and detachment rates which vary greatly both between sites and within sites for different floods (Table 4.4.3).

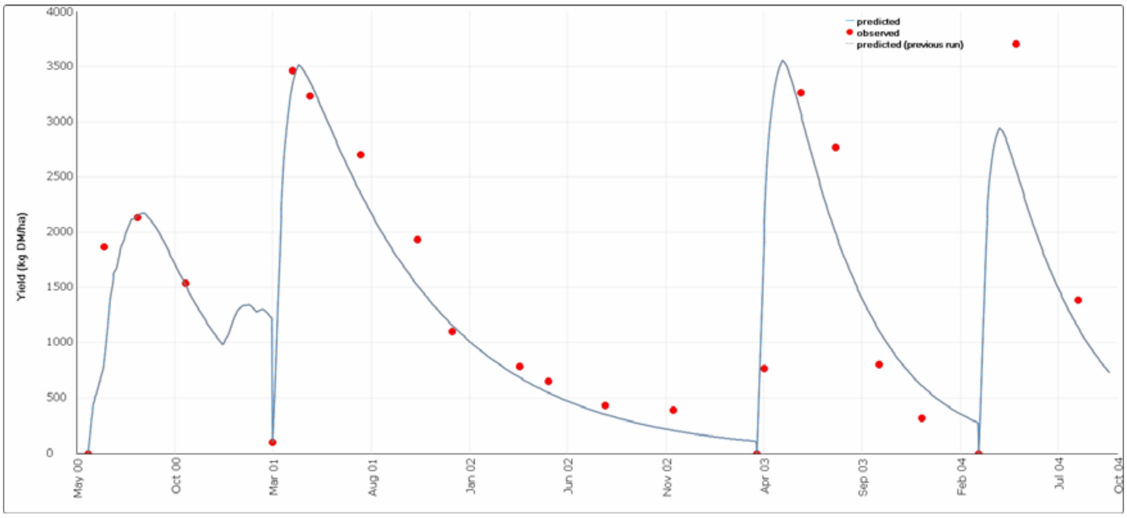


Figure 4.4.1. Observed and simulated pasture yield at Glengyle following four growth 'pulses' associated with four floods.

Table 4.4.3. Summary of key parameters found in calibrating each of four growth pulses at Glengyle. Parameters include plant available water capacity (PAWC), potential regrowth rate, rate of detachment of dead material.

Site	Pasture Species	PAWC (mm)	Potential Regrowth Rate (kg/ha/day)	Detachment Rates (kg/kg/day)	Peak Yield (kg/ha)
Glengyle (Flood 1)	Nardoo, Sedge	223	85	0.008	2160
Glengyle (Flood 2)	Peabush	223	190	0.005	3770
Glengyle (Flood 3)	Sorghum	223	190	0.009	3470
Glengyle (Flood 4)	Sorghum	223	190	0.009	3550

4.5 The analysis of grazing trial data to test the model's capability and demonstrate new approaches to calculating pasture utilisation

4.5.1 Calculating animal intake and pasture utilisation in grazing trials

A major issue in analysing the results of grazing trials is how to extrapolate the findings to other locations and land-types. Several studies have indicated that the calculation of utilisation of pasture growth (and the relationship with animal production and resource condition), is a unifying concept across trials (McKeon and Rickert 1984, McKeon *et al.* 1990, Johnston *et al.* 1996, Day *et al*, 1997, Hall *et al*. 1998).

The major progress in developing a better model has been the evaluation of calculation of pasture utilisation by G. Stone and G. Fraser in cooperation with P. O'Reagain. Pasture utilisation is calculated as the ratio of animal intake to pasture growth. The calculation of pasture utilisation is a major objective of using GRASP to analyse grazing trials. The Wambiana grazing trial (P. O'Reagain and colleagues NBP.318 Sustainable Grazing in the Tropical Savannas - Wambiana) has been used to provide an example of this type of calculation as initial work had already been conducted on parameterisation of individual land-types and collation of animal liveweights. In the project, G. Fraser used the GRASP Calibrator to update parameterisation of the SWIFTSYNpD data collected at seven land-type sites within the trial. A simulation of paddock pasture growth was then developed using the relative areas of each land-type for each paddock.

G. Stone examined the different approaches available for estimating animal intake, such as: simple daily estimates based on metabolic body weight; the intake equation of Minson and McDonald (1987) using liveweight gain and liveweight; a new algorithm using inputs of digestibility liveweight gain and liveweight (QuikIntake, McLennan and Poppi 2004); and intake estimates from GRASP based on converting animals to weaner equivalents.

After review it was decided to use 'QuikIntake', the MLA funded spreadsheet model produced by S. McLennan and D. Poppi (2004) to calculate animal intake. There are 10 inputs that can be used to calculate intake, including: breed; sex (steer/cow); standard reference weight; age; potential highest liveweight; current liveweight (LW); liveweight change/day (LWC/d); dry matter digestibility (DMD); distance walked and degree of terrain. Whilst other equations include observed liveweight change, the approach of McLennan and Poppi (2004) has the advantage of including pasture digestibility, an important determinant of intake. The calculation procedure is given in Appendix 9.10. An example of calculated utilisation for a single paddock at Wambiana is given in Figure 4.5.1.

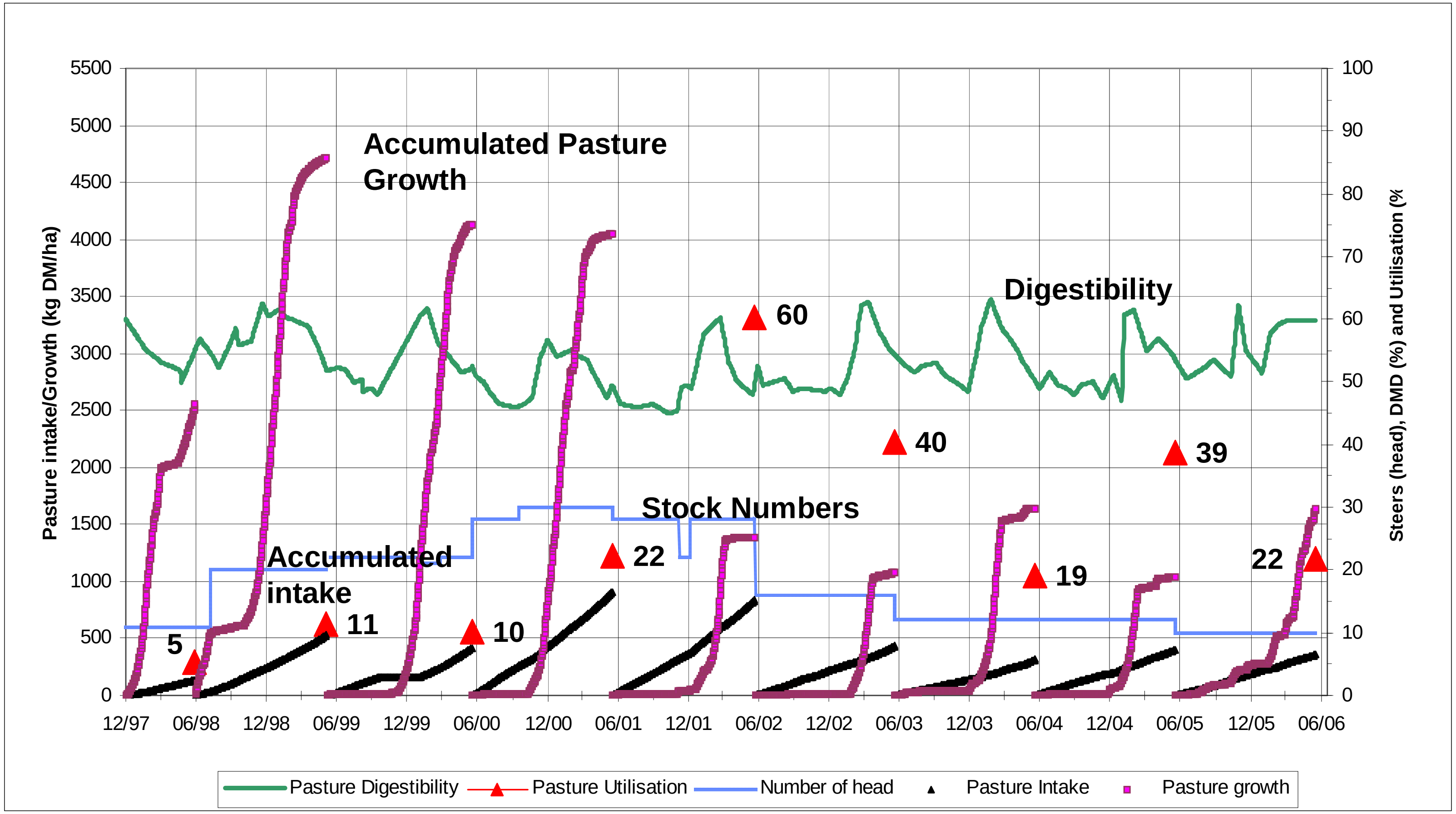


Figure 4.5.1. Time series of accumulated pasture growth, animal intake, digestibility and annual utilisation (G. Stone, G. Fraser, P. O'Reagain and J. Bushell unpublished data). The values are for Paddock 1 at Wambiana grazing trial in which stocking rate was adjusted each year.

The project team envisage that this approach could be repeated for all grazing trials (e.g. Galloway Plains) where most of the information (as described above) can be provided. In this way, there will be a standardised approach to be applied to grazing trials past, current and future to calculate utilisation.

This study suggests that the outputs from all trials can be assimilated and compared using the same process. This is a first in grazing trial analysis and a major step forward in terms of comparing grazing trial results on the same basis. Thus it supports the concepts delivered in GLM.

Case study: Calculation of utilisation for paddocks in Wambiana grazing trial (NBP.318, P. O'Reagain et al. 2008)

The Wambiana grazing trial was analysed to calculate pasture utilisation. The procedure developed provides a case study in the use of the GRASP model and the GRASP Calibrator, as well as additional models (QuikIntake). Each paddock in the Wambiana grazing trial has several land-types. P. O'Reagain and colleagues have carried out SWIFTSYNpD pasture growth on seven land-types. G. Fraser and K. Day parameterised GRASP particularly concentrating on differences in soil fertility. The parameter sets were then used to simulate pasture growth over the period of grazing for the trial (1997 to 2006). The proportional area of each land-type in each paddock was then used to calculate an overall daily paddock pasture growth. The simulated growth does not include the effects of grazing in terms of decline in resource condition. G. Stone used trial data which included stocking rate, steer liveweight, liveweight gain and pasture digestibility to calculate daily feed intake from the QuikIntake model (McLennan and Poppi 2004) described above. Pasture utilisation (i.e. the ratio of animal intake to pasture growth) was then calculated for each animal draft or year (by treatment/paddock for the duration of the trial). The calculated values were then used by P. O'Reagain to interpret animal production and pasture resource changes.

An alternative calculation of utilisation would involve the simulation of pasture growth that includes the impacts of grazing on resource condition. These effects include changes in grass basal area, species composition and infiltration attributes of the soil surface. Calculation of pasture growth using this approach would use actual paddock measurements, including measured pasture yields and pasture basal area data. This alternative form of calculation will be carried out once the pasture data have been collated and each paddock calibrated with the GRASP model.

4.6 The collation of land-type parameters and the creation of a library of parameter sets

4.6.1 Procedures for developing land-type parameter sets

A major application of the model as stated in the project objectives was to support the development and delivery of the Grazing Land Management package (GLM) through the simulation of pasture growth for different land-types. In GLM, C. Chilcott and colleagues used selected land-type parameters for the Burnett, Burdekin, Victoria River District, Mitchell Grasslands and Western Downs to provide simulations of pasture growth as part of GLM. Parameter sets previously derived by Day *et al.* 1997 (DAQ124 RIRDC) were used to develop initial land-type parameters for these districts. The next stage was to upgrade these parameterisations and to provide parameter sets for central Queensland. A major challenge for the GRASP project was that the GLM delivery for central

Queensland was due in May/June 2005 which preceded the completion of the major modelling development milestone (Milestone 7, February 2006). To address this issue, C. Chilcott and G. McKeon developed two procedures summarised in Appendix 9.11.

Independent test of GRASP in ranking land types

The pasture growth data collected at Brian Pastures (Gayndah, South-east Queensland) provides an independent test of the usefulness of GRASP in simulating the difference between land-types. As described in Section 4.4.2, parameters for seven sites were derived from data collected from 1986/87 to 1992/93 (Day *et al.* 1997). The seven sites covered a range of soil textures, fertility and pasture species. Simulations of pasture growth for the period 1993/94 to 2003/04 suggested that, although pasture growth was overestimated, the ranking of sites was maintained (Figure 4.6.1). Thus, it is expected that parameter sets derived from pasture growth studies can capture some of the key attributes that discriminate between land-types. Further analysis of this dataset is continuing.

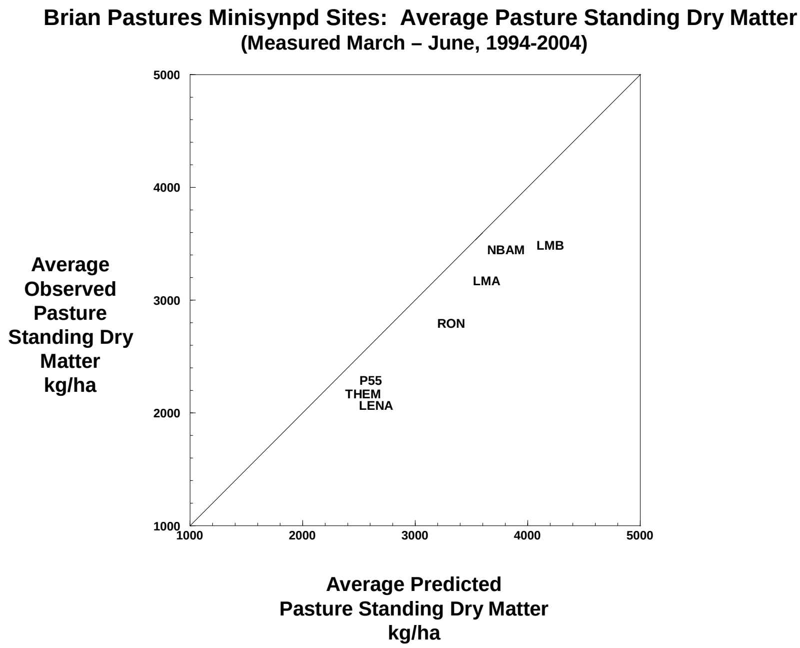


Figure 4.6.1. Comparison of simulated and observed pasture growth at 7 exclosure sites at Brian Pastures, Gayndah. The parameters for GRASP were derived from data collected from 1986/87 to 1992/93 (Day *et al.* 1997). The measurements were taken at the end of each growing season from 1993/94 to 2003/04 (11 years). Values for each site have been averaged across years. Site descriptions are given in Appendix 9.15. The sites are: stony prarie soil on andesite (LMA, LMB, THEM); black earth on basalt (RON and NBAM); linear gilgai clay on andesite (P55); and coarse sand on granite (LENA).

A matrix/factorial approach to representing land type attributes

The existing parameter sets collected by Day *et al*. (1997) provided an initial base. A matrix/factorial approach was also developed which summarised the existing parameter sets in terms of soil and pasture attributes (Tables 4.6.1 and 4.6.2). The matrix/factorial approach provided a greater understanding of the differences between land-types in terms of soil and pasture attributes, and was implemented in the GRASP Calibrator to provide users with a rapid introduction to the representation of land-type attributes.

Table 4.6.1. Parameters for land-type attributes: hydrology and soil moisture parameters

Attributes	Options	Parameters				Comments
Hydrology	1. Free draining 2. Scanlan runoff 3. Run-on 4. Other	Runoff option (P270) = 0 Runoff option (P270) = 1 Need new rainfall file (A) Other runoff coded				(A) A two step procedure is required to calculate a new rainfall file
Depth of Pasture Soil Moisture Zone (mm)		**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**	(B) Depth of Layer 3 is 100cm but available water range of Layer 3 is calculated as 10% of potential available water
	1. Shallow (60cm)	100	400	500 (B)	0	
	2. Average (100m)	100	400	500	0	
	3. Deep (150cm)	100	400	1000	3500	
Texture Available water range (mm/10cm)		**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**	
	1. Sand	10	10	10	5	
	2. Average	15	15	10	5	
	3. Clay	25	20	15	10	
	4. Duplex	(C)	(C)	(C)	(C)	(C) Yet to be calculated
Texture (continued) Lowest Soil Moisture i.e. Wilting Point (%cc/cc)		**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**	(D) Layer 4 is specified as an available water range and hence does not have a lower soil moisture value
	1. Sand	1	1	1	(D)	
	2. Average	10	10	10	-	
	3. Clay	15	15	15	-	
	4. Duplex	(C)	(C)	(C)	-	

Table 4.6.2. Parameters for land-type attributes: soil fertility and pasture species (E)

Attributes	Options	Parameters			
Soil Fertility		**Potential N Uptake (p99, kgN/ha)**	**N Uptake per 100mm (p98, kgN/ha/100cm)**	**Initial N Uptake (p97, kg N/ha)**	**Potential Regrowth per unit of Basal Area (p6, kg/ha/day)**
	1. Very poor	10	4	3	2.0
	2. Poor	15	5	4	2.0
	3. Average	20	6	5	3.5
	4. Good	25	8	6.25	5.0
	5. Very Good	30	10	7.5	6.5
Pasture Species		**Minimum % N (p101, p102)**	**Transpiration Efficiency (p7, kg/ha/mm @ 20hPa)**	**Yield at 50% Cover (p46, kg/ha)**	**Height of 1000 kg/ha (p96, cm)**
	1. Leaf Producers	0.88, 0.98	12.0	(E)	(E)
	2. Average Leaf/stem	0.68, 0.78	13.5		
	3. Stem/Producers	0.40, 0.50	15.0		

(E) Other species attributes are yet to be linked to pasture species.

The components of the matrix or factorial are as follows:

(1) Hydrology

Two options available in 2006 were: free draining soil; and Scanlan's runoff model derived from soils in Charters Towers region. A third option representing flood plain or run-on sites is being developed as follows. Up to now run-on situations have been simulated by first simulating runoff and then adding the runoff to the daily rainfall file to produce a new rainfall file for the run-on location. This requires a two-step procedure and has the explicit assumption that the run-on occurs on the same day as the runoff generated by the other components of the landscape. This approach also assumes that the area of the landscape that contributes runoff is the same area as the run-on component of the landscape. Despite the weakness in these assumptions this procedure has nevertheless provided a plausible simulation for several floodplain or run-on sites. As runoff models for other soil types are developed and parameterised as described previously (Appendix 9.7) they will be included as options.

(2) Soil depth

GRASP simulates soil moisture for 4 soil moisture layers: layers 1 (0-10cm), layer 2 (10-50cm) and layer 3 (50-100cm). Layers 1 to 3 are available to both pasture and trees whilst layer 4 (>100cm) is only available to trees. The three soil depth options for the pasture soil moisture zone are: shallow (100cm) but restricted available water in layer 3, average (100cm) and deep (150cm). For shallow and average pasture depths, trees are assumed to occupy the same soil depth and the ‘thickness’ of layer 4 is assumed to be zero. However for the deeper soil, trees are assumed to be able to extract moisture to a depth of 5m.

(3) Soil texture

For each of the four layers used in GRASP an available water range (e.g. Field Capacity minus Wilting Point) is specified in terms of millimetres per 10 centimetres (mm/10cm). The options are: (1) sand (10mm/10cm), average soil (15mm/10cm), and clay (20-25mm/10cm). Lower values are used for layers 3 and 4 (Table 4.6.3). For the shallow soil, the low value for layer 3 represents cracks and root channels in the 50-100cm zone rather than texture as such. A fourth option for duplex soils is yet to be developed. The parameters associated with available water range and soil depth are yet to be analysed in a form that would allow a composite duplex soil profile to be provided.

(4) Fertility

Five levels of site fertility, ranging from 10-30 kg N/ha, are available as represented by potential nitrogen uptake and associated parameters.

(5) Pasture species

Three types of pasture species are available: stem producers, average perennial grasses, and leaf producers. The associated parameters are minimum percent nitrogen and transpiration efficiency. The hypothetical link between leaf and stem partitioning and transpiration efficiency is yet to be researched and is regarded as a plausible speculation at present. Other species-related parameters that are likely to affect leaf/stem morphology are cover/yield and height/yield relationships, and detachment rates. These parameters are yet to be calculated.

4.6.2 Land-type parameter sets

The simulated pasture growth tables from GRASP for different land-types have provided support to the development and delivery of GLM workshops across Queensland and the Northern Territory. The development of parameter sets describing soil and pasture attributes is a similar endeavour to the development of sub-models of biophysical processes in GRASP. Thus, the parameter sets developed for individual land-types are often described as ‘models’ by users of the parameter sets.

The development of land-type models using the above procedures has culminated in parameterisation of approximately 250 land-types across Queensland and Northern Territory (see Table 4.6.3). There is potential to develop a further 40 parameter sets for land-types in some GLM regions that were conducted (or planned) in 2007/2008 (e.g. Inland Burnett, Mary, Darling Downs, Border Rivers). Following evaluation of modelled outputs used at GLM workshops, a small number of models need to be revised so as to match producer expected outputs (e.g. Inland Burnett). More generic models used in parameterisation of land-types include parameter sets for annual grass, buffel grass and 'average' native pasture. A comprehensive list of land-types, the regions they occur, model number and code (.mrx), and model development notes is described in Appendix 9.11.

Table 4.6.3. Table of land-types, parameter sets (called 'models') and potential model development for GLM regions within Queensland and Northern Territory (NT).

GLM Regions	Land-types	Parameter Sets	Areas for further development	
	No.	No.	New land-types under development	Potential model development
Coastal Burnett	12	12		
Inland Burnett	20	12		8
Mary	7	7	yes	up to 7
Moreton	12	12		up to 7
Darling Downs	9	7	yes	up to 6
Border Rivers	(A)	7	yes	up to 5
Maranoa and Balonne	18	19	yes	4 (buffel)
Mulga	11	16 (includes 4 buffel)	yes	3
Mitchell Grass Downs	16	16 (includes 1 buffel)		
Channel Country	13	9 + 3 floodplain models		1
Desert Uplands	13	17 (includes 4 buffel)		
Fitzroy	37	36		2
Mackay Whitsundays	9	14 (includes 5 improved)		
Southern Gulf	17	17		1
Northern Gulf	14	15 (includes 1 buffel)		
Wet Tropics	(A)	8		
Burdekin	18	17	yes	22
Victoria River District (NT)	8	8		
Alice (NT)	5	5		
Total	**251**	**250**		**66**

(A) to be developed.

Future developments: linking other parameters to land-types

As discussed previously a current feature of simulations with the low fertility land-type parameter sets is the low year-to-year variation in simulated pasture growth. Discussions with project colleagues (A. Ash, M. Quirk, C. Chilcott) suggested that these land-types should have increased sensitivity to soil moisture stress because of low root volume. Sensitivity to soil moisture stress is also likely to increase with increasing grazing pressure. The datasets compiled above by CSIRO SE (J. McIvor) and the various QDPI&F grazing trials (Wambiana, Galloway, Keilambete) will allow this hypothesis to be tested and implemented in the land-type parameter factorial/matrix.

An important development in parallel with the GRASP modelling project has been the successful completion of a PhD Thesis by M. Cobiac ‘Predicting Native Pasture Growth in the Victoria River District of the NT’. The PhD was accepted on January 21 2007. In his Thesis, M. Cobiac calibrated GRASP for 21 sites in the VRD region of the Northern Territory. He demonstrated the importance of nutrient limitations in controlling pasture growth and the difficulties in estimating key parameters, (potential nitrogen uptake and minimum %N) given the variability that exists with land-types. He also indicated the difficulties that GRASP has with infiltration in cracking clay soils. Land-type pasture growth analysis in GLM has initially relied on parameters derived from pasture growth trials (GUNSYNpD, SWIFTSYNpD). M. Cobiac’s Thesis indicates the difficulty and variability resulting from this approach. Thus the current approach of adopting a more general view of ranking land-types and choosing associated parameters from the land-type matrix/factorial would appear appropriate.

4.7 The link between GRASP and the new CSIRO SE ENTERPRISE model

GRASP simulates both pasture and animal responses to different grazing management options. Animal production output is in annual liveweight gain (kg/head and kg/ha) but for producers to make full use of the implications of grazing management options it is important that this production data be put in an enterprise context (herd dynamics, reproduction, mortality, growth, turn-off etc). To achieve this GRASP has been linked to an enterprise level spreadsheet economics model (ENTERPRISE). Copies of the model will be made available to those who are interested in using it. Presentations on the use of GRASP-ENTERPRISE in assessing seasonal climate forecasts have been given at the CSIRO SE Climate Conference held on the Gold Coast in 2005.

The links between GRASP and ENTERPRISE have been made using the Spaghetti version of GRASP which has customised output for this task. CedarGRASP is yet to be 'customised' to make the same links. However no difficulties are anticipated in completing this link.

The broad approach followed in developing ENTERPRISE involved a combination of experimental data (e.g. Ash *et al.* 1995) and a modelling approach (e.g. MacLeod and McIvor 1998). The general modelling framework is presented schematically in Figure 4.7.1.

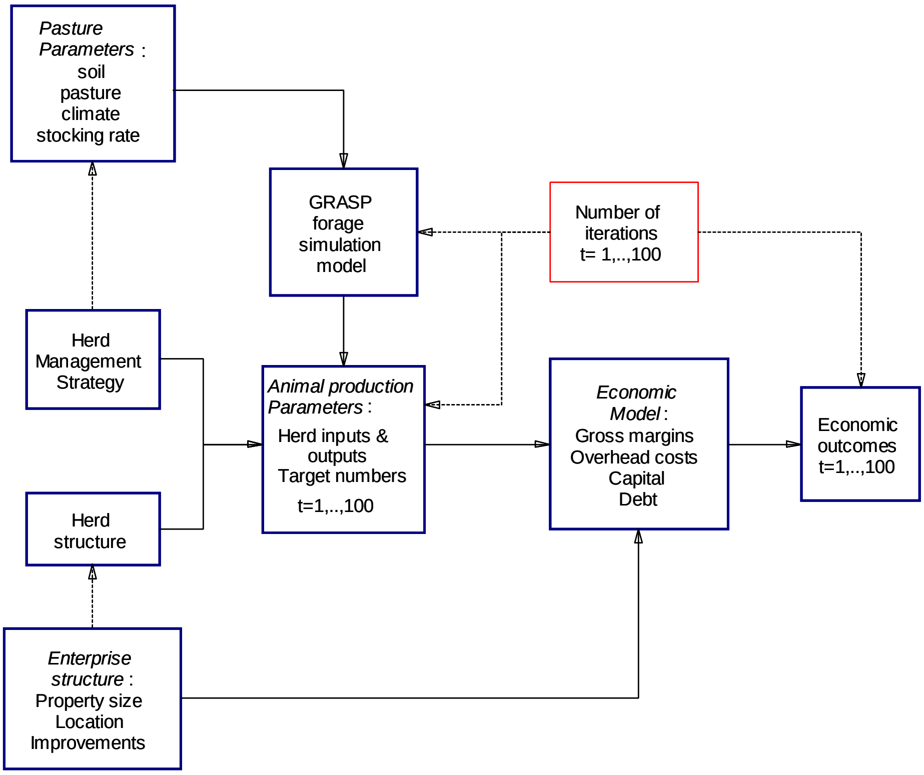


Figure 4.7.1. Overall modelling framework that links output from the GRASP model through to herd dynamics and enterprise economics. The model runs for 100 years (t=1,…,100). The figure has been previously presented in MacLeod and Ash (2001). The inputs from GRASP are stocking rate and liveweight gain per head.

The model mimics the production and economic outcomes of the enterprise for a simulation run of 100 years subject to a range of management strategies – the model presently operates on a maximum of 3 strategies simultaneously. The economic outcome for a given year in the simulation run is assessed using a whole-enterprise budgeting technique (Makeham and Malcolm 1993) and provides estimates of total gross margin and return on capital and management (net profit) for an array of equity levels.

Animal production data (liveweight gain/head/year) and long-term stocking rate (animals/km^2) based on a specified average utilisation rate over 100 years are predicted from GRASP and branding rate and mortality rate estimates are used to calculate the number and market quality of stock that are available for sale from the herd. Market price and direct cost data are combined with the livestock sales and purchases data in each year of the simulation run, to derive an estimate of the total gross margin for each herd management strategy. The direct costs used to calculate total gross margin include both husbandry and supplementary feeding costs. Total gross margin is converted to net profit (return to management, capital and labour) by subtracting an estimate of overheads costs for the enterprise. The structure of the economic computations within the model is presented schematically in Figure 4.7.2. The results for the 100 year model simulation are summarised for a range of key output parameters (Appendix 9.16) to provide mean estimates of their values and where appropriate additional measures of maximum or minimum values and the proportion of years of the run in which the parameter might have exceeded or failed to meet some critical threshold (e.g. maximum gross margin, % of years in which net profit was negative, % of years in which stock were fed drought rations etc).

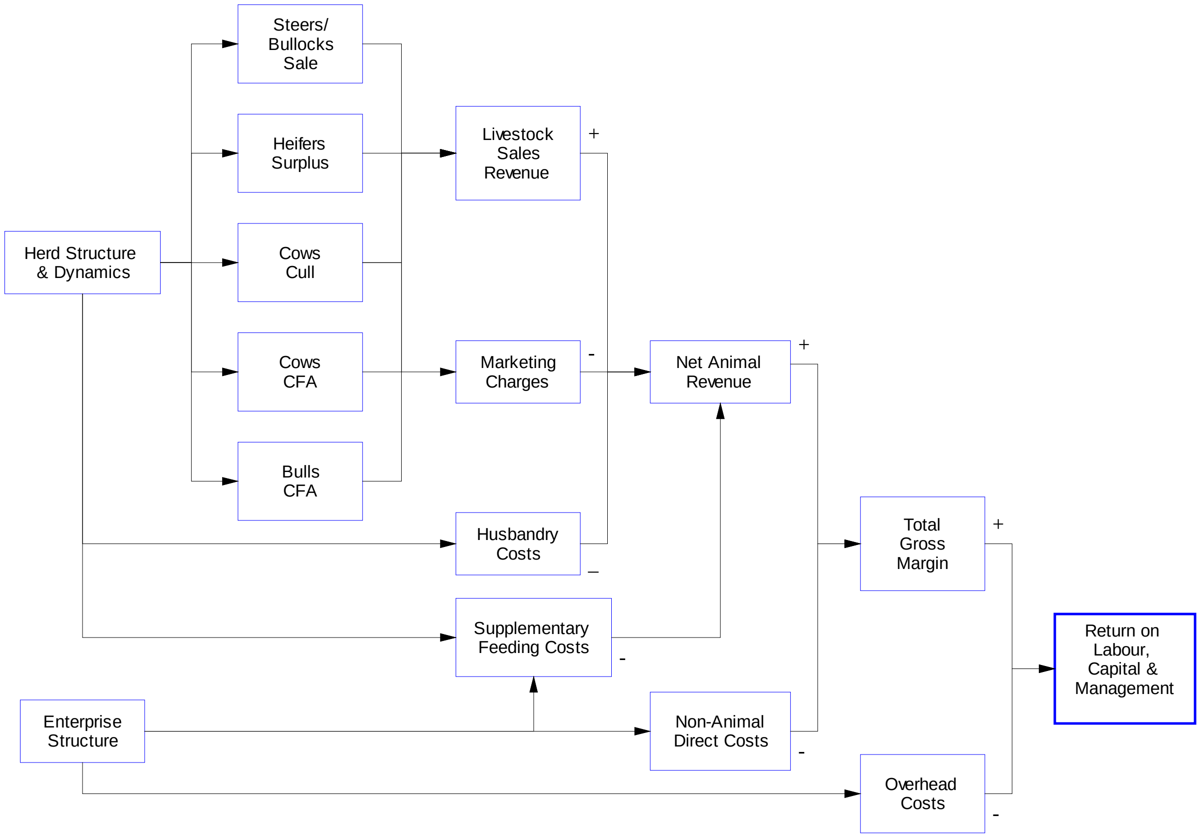


Figure 4.7.2. Herd dynamics and economic computations within the spreadsheet economic model, ENTERPRISE. The model runs for 100 years (t=1,…,100). The figure has been previously presented in MacLeod and Ash (2001). CFA refers to cast for age, i.e. animals culled at a specified age.

A major feature of ENTERPRISE is that it allows stocking rate decisions, based on simulated pasture growth, to be evaluated in terms of financial performance. Thus, ENTERPRISE calculates the impact of year-to-year climate variability on economic indicators, such as gross margin per hectare (Figure 4.7.3).

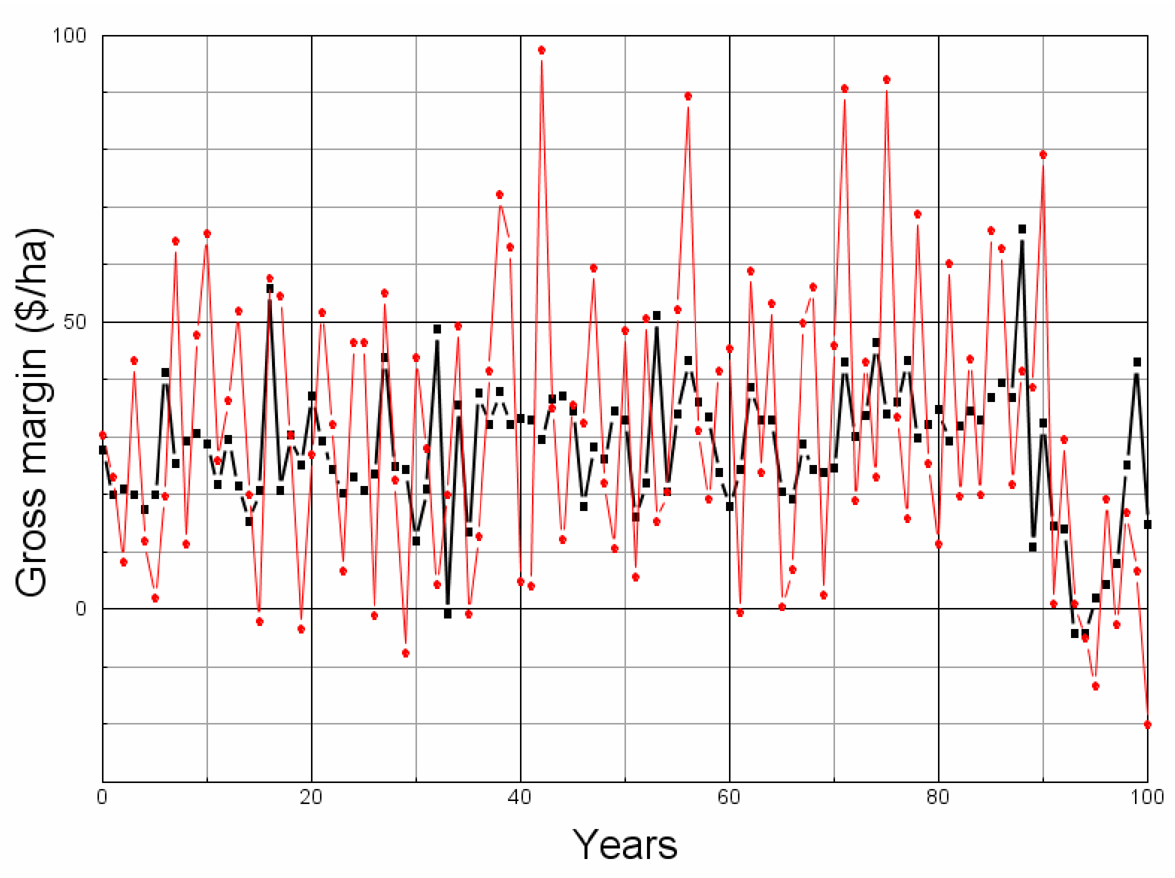


Figure 4.7.3. ENTERPRISE simulation of gross margin per hectare for 100 years at Charters Towers. The simulation is for two grazing management strategies with different stocking rate decision rules. The black line (black squares) is for a constant stocking rate. The red line (red circles) is for a strategy linking stocking rate to a climate forecast based on sea surface temperatures (MacIntosh *et al.* 2005). The herd dynamic strategy limited year-to-year change to + and – 20% (see Appendix 9.16 for more detail).

4.8 Project administration across the three collaborating organisations (QNR&W, CSIRO SE, QDPI&F) and liaison with other States and institutions

The project coordinated modelling applications funded under other MLA projects such as:

- NBP.329 Sustainable Grazing in Channel Country Floodplains (D. Phelps *et al*.);
- NBP.328 Increasing Uptake of Drought Management Options to Optimise Pasture Recovery Following Drought (D. Orr);
- NBP.318 Testing and developing principles and management guidelines for the sustainable management of the seasonably variable tropical savannas (P. O'Reagain *et al*.); and
- NBP.316 Assessing the Value of Trees in Sustainable Grazing Systems (C. Chilcott *et al*.).

The GRASP model is also a component of the CRC Tropical Savannas project Property Decision Support and Risk Management Tools for Grazing Management which uses the PaddockGRASP version of the model developed by P. Timmers in the GRASP modelling team.

The major project administration involved the development of an Memorandum of Understanding (MOU) with QDPI&F and a sub contract with CSIRO SE. The purposes of the MOU and sub contract were to provide a more formal base for the exchange of data and modelling that has already occurred (based on goodwill) over the last 15 years.

To meet the objectives of the project, QDPI&F carried out the following tasks and supplied:

1) Data collected from grazing trials and other field trials relevant to GRASP model development and parameterisation. Grazing trials included Keilambete, Wambiana, Glentulloch and Galloway Plains. Data sets included rainfall, other climate variables, stocking rate history, pasture management history (including burning, tree clearing, sowing legumes), pasture and animal production measurements, runoff and soil loss measurements, soils/land-type maps of trials, preliminary and published reports and access to grazing trial diary information and expert opinion in written or verbal format;
2) Data from other QDPI&F trials and data collected considered useful for GRASP model development and parameters (e.g. Drought Recovery, Producer Demonstration Sites, Land-type analysis);
3) Land-type description in terms of parameters to link with GLM and other QDPI&F projects (e.g. AgSIP);
4) Written contributions on relevant sections to final report and GRASP model description;
5) Evaluation by QDPI&F staff of simulations of grazing trials and land-types and specifications on modelling requirements;
6) Acknowledgement of QNR&W contribution to the GLM process;
7) QDPI&F staff for training in use of the GRASP model and parameter sets – with cost of training (accommodation, travel expenses) at QDPI&F expense.

To meet the objectives of the project, CSIRO SE carried out the following tasks:

1) Supplied data relevant to the GRASP model collected in major grazing trials including Manbulloo, GLASS and ECOSSAT.
2) Linked the GRASP model to CSIRO SE's herd/economic model ENTERPRISE.
3) Prepared papers for submission to refereed journals on model evaluation and simulation results (MacLeod *et al.* 2004, McIntosh *et al.* 2005, Cullen and Ash 2007).
4) Provided reviews of model documentation, milestone reports and final reports.
5) Provided written material for final report.
6) Provided appropriate staff (C. McDonald, J. McIvor, M. Stephens) for training at CSIRO SE expense with the GRASP model

Tasks yet to be completed include review of key processes in GRASP and training for other staff in use of ENTERPRISE model. This is expected to occur in May 2008.

Thus the project brought together three major collaborating agencies covering a wide range of scientific experience, field data, and modelling expertise in northern Australia.

4.9 Communication of the project and the outputs through the grazing land management education package

The GLM Education package has been the platform for communication with industry. Pasture growth tables derived for different land-types were provided from GRASP simulations. Presentations of components of the model and simulation results, along with other material such as remote sensing products and review of historical degradation episodes, were presented to industry groups and representatives by members of the project team.

1) 'Building Blocks for Sustainability', Kingaroy 18th July 2005 – AgForce 2005 State Conference 'Success through Innovation – Building Better Businesses'
2) General talks, Roma 8th March 2005 – Maranoa-Balonne Catchment Management Authority March 2005 Catchment Workshop

The GRASP workshops described previously (including three 3-day workshops) were the major form of communication with pasture scientists across northern Australia and rangeland areas. These workshops included training in the use of the model and presentations on the biophysical theory behind GRASP. Participants were provided with examples of practical applications in terms of analysis and grazing trials, calculation of safe carrying capacities, and impacts of climate change (a list of PowerPoint's that were used in the workshops is given in Appendix 9.12).

Publications including the use of GRASP produced during the project are as follows:

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**: 49-71.

McIntosh, P., Ash, A. and Stafford Smith, M. (2005). From oceans to farms: using sea-surface temperatures in agricultural management. *Journal of Climate* **18**: 4287-4302.

Cullen, B.R. and Ash, A.J. (2007) Interactions between seasonal forecast skill and climate variability in agricultural systems. Submitted to Australian Journal of Agricultural Research.

Cowley, R.A., Blomfield, C.M., Tarrant, M.B. and MacDonald, N. (2008). Current levels of utilisation of pasture on extensive cattle properties in northern Australia. VIII International Rangeland Congress 2008, Hohhot, Inner Mongolia, China 29 June 2008.

Hacker, R.H., Thompson, T.J., Murray, W.K. and Timmers, P.K., 2006. Precision management systems for pastoral livestock procedures. Australian Rangeland Society 14th Biennial Conference, 3 – 7 September, 2006, Renmark, South Australia, pp 198–201.

Alemseged, Y., Hacker, R.H., Timmers, P.K. and Smith, W.J., 2006. Estimation of paddock-level pasture production using PaddockGRASP in western NSW. Australian Rangeland Society 14th Biennial Conference, 3 – 7 September 2006, Renmark, South Australia, pp 37–40.

Jones, P., Silcock, R.G. and Stone, G. (2008). Grazing land in “A” condition is stable and resilient. Abstract for Australian Rangeland Conference, Charters Towers, 28 September 2008.

Stone, G., Fraser, G., O’Reagain, P., Timmers, P. and Bushell, J. (2008). A new methodology for the calculation of pasture utilisation for grazing lands. Abstract for Australian Rangeland Conference, Charters Towers, 28 September 2008.

Cobon, D.H., Bell, K.L., McKeon, G.M., Clewett, J.F. and Crimp, S. (2005) Potential climate change impacts on beef production systems in Australia. Proceedings XX International Grassland Congress, Dublin pp 557.

GRASP also provides a basis for assessing the impact of climate change on pasture production. Workshops and reports describing the use of GRASP and the implications for the grazing industry are currently being planned (May 2008).

5 Success in achieving objectives

The objectives of the project were to:

1) Develop an updated and fully documented version of the pasture growth model GRASP so that it can be used by pasture scientists across northern Australia;
2) Support the model with a comprehensive parameter library for different land-types in northern Australia; and
3) Train more than twelve pasture scientists in the use of the model and its supporting tools.

The following tasks were successfully achieved:

1) Improved computing code and modelling environment were developed;
2) Approximately forty pasture scientists were trained in three major workshops in the use of the model and the new interfaces;
3) The model was improved mainly by the addition of alternative runoff models and sub-models addressing the varying dilution of available nitrogen by pasture;
4) New pasture growth datasets and historical grazing trial data from across northern Australia were added to the database;
5) New approaches to calculate animal intake and utilisation in grazing trials were developed and demonstrated;
6) Parameter sets were developed for over 300 land-types in Queensland and close liaison established with the pasture science teams in the Northern Territory and Western Australia who are conducting similar exercises;
7) The pasture growth model GRASP has been linked to the CSIRO SE herd/economics model ENTERPRISE;
8) A more formal network of pasture scientists across States and institutions was established; and
9) The results of the model development have been communicated through the Grazing Land Management education package, on-line model documentation, workshops for pasture scientists, and publications by CSIRO SE.

The achievements of the project provide a basis for the future development of models of pasture growth and their application to industry.

Evidence of the success of the project is provided by:

1. A better modelling environment by the development of new GRASP code and a new interface called the GRASP Calibrator. In particular, the GRASP Calibrator provided users with the capacity to:

    - Easily run simulations for different land-types and climate stations;
    - Being able to display graphically, all variables simulated by the model including soil water, hydrological components, pasture growth and dry matter flow, nitrogen uptake and concentration, tree water use and other attributes, stocking rate and other grazing variables, and aspects of degradation risk (utilisation and soil loss);
    - Carry out conditional probability analysis of simulated variables especially pasture growth;

- Compare graphically observed and simulated variables particularly important for analysis of pasture growth and grazing trial data; and
- Compare graphically observed pasture growth to a range of variables such as simulated growth index, and thus facilitate parameterisation.

2. Self assessment by workshop participants of improved skills in using the GRASP model (Section 4.2.3, Appendices 9.2, 9.3, 9.4 and 9.5);
3. Statements from managers of participating agencies (R. Cowley, R. Hacker and I. Watson, Section 4.2.3 and 4.2.4).

6 Impact on Meat and Livestock Industry – now and in five years time

Graziers in northern Australia face the challenge of matching stocking rate to pasture growth whilst maintaining resource condition. Thus there has been a major need to supply the grazing community and supporting advisors and agencies with calculations of pasture growth to different land-types and climatic conditions. A major challenge that pasture scientists face in addressing these needs is to estimate pasture growth from field studies including pasture growth exclosures and grazing trials. Over the last 30 years simulation models have been developed of pasture growth to allow results from field trials to be extrapolated in time and space and to also simulate the different effects of grazing management decisions on the pasture resource. The simulation model GRASP is a soil water-plant growth-grazing model developed for northern Australia rangeland pastures. Although GRASP had been used in many applications over the last 30 years, there was a need to provide a more up-to-date computing code, model interfaces, library of parameter sets and training in its use so that a wider range of scientists would apply the model to industry needs.

The Grazing Land Management education package provides a powerful tool to allow individual graziers to assess pasture growth for individual land-types on their properties. The GRASP model provides an approach to estimate pasture growth for a wide range of combinations of soils and pastures and tree density for many locations in northern Australia. Thus an expected impact is that graziers will have the information necessary to better match stocking rates to pasture growth either over long timescale (e.g. 30 years) or at shorter timescales (less than 10 years). The simulations provided by GRASP also allow information to be presented for climate risk assessment including the impact of the phases of the El Nino Southern Oscillation phenomenon on seasonal pasture growth.

The pasture model GRASP has also been used to simulate the impact of climate change and varying tree density and hence provides an approach to estimate the impact of these possible changes that may be occurring or are likely to occur over the next five to ten years.

7 Conclusions and recommendations

7.1 Summary

The major goal of the project was to provide a sound basis for the use of GRASP by pasture scientists in support of the GLM education package and other applications for the grazing industry, (e.g. climate change impacts). The project was successful in reaching this goal. However, there are a number of issues that need to be addressed so that applications of GRASP can continue to be supported.

Complex software and modelling projects such as GRASP require resources for updating and servicing of code, continuing evaluation of accuracy of outputs, training and refreshing of users, servicing of enquiries, and development to support emerging issues. The components of GRASP that need to be maintained are:

1) The relevance of applications to the grazing industry including emerging issues such as climate change impacts, woodland management, and provision of information/knowledge tools to individual graziers and their advisors; and
2) The commitment of relevant agencies to provide a ‘home’ for GRASP, its committed scientists and the delivery of outputs from GRASP’s use.

1. Current and future applications

The GRASP model and supporting components could be improved in the following areas to address the emerging needs of the grazing industry and supporting science:

1) The interaction of land-types, woodland management and climate variability in terms of safe utilisation rates and degradation risk;
2) The impact of climate change on pasture and animal production;
3) The continuing organisation and repository of grazing trial data and analyses for current application;
4) Evaluation of new grazing management options, particularly those being advocated in terms of increasing soil carbon; and
5) Provision of a rigorous systems analysis of complex issues such as woodland management.

2. Future ‘home’ for GRASP and supporting parameter sets

During the period of the project, considerable changes occurred in the organisational structure of agencies and in the personnel involved in supporting the use of GRASP. The success of GRASP in supporting industry needs has, in the past, been due to its relevance, and the goodwill and commitment of agencies and the individual pasture scientists involved. With the change of the ‘home’ unit (Climate Impacts and Natural Resource Systems, Queensland Department of Natural Resources and Water) to the Queensland Climate Change Centre of Excellence (QCCCE) in the Queensland Environmental Protection Agency, it will be important to facilitate the maintenance of a ‘home’.

A major achievement of the GRASP project (and related projects) has been the development and testing of soil/pasture parameter sets for land-types and grazing trials. These parameter sets provide a powerful basis for future users. Their continued availability and collation are important issues that need support and institutional commitment.

3. Supporting network of pasture scientists

A result of the project was the development of a wider network of pasture scientists across northern Australia who were contributing to, evaluating, and using the outputs from GRASP. The network is across many science organisations with representatives from State and Commonwealth agencies. This network provides, by operating in the same modelling environment, efficiency in terms of delivery of applications to industry and a basis for sharing knowledge in terms of pasture science.

It was particularly encouraging that the Northern Territory SWIFTSYNpD team (led by R. Cowley) had already demonstrated a capacity to carry out detailed field studies on over 25 sites providing the necessary information to derive parameters for simulating pasture growth. This expertise, so well demonstrated by the Northern Territory team, indicated that capability in using pasture modelling and supporting field data collection exists more widely than just in Queensland. Given the interest also shown in Western Australia (P. Novelly and C. Chilcott), MLA might consider how it could further support this emerging network of pasture scientists involved in systems analysis and grazing system modelling.

There is an opportunity for MLA to facilitate the continuation of the GRASP users network by providing funds for collaborating agencies.

4. Training, re-training, support and development of self reliance for GRASP users

Like other biophysical models, the tasks and knowledge involved in GRASP are very complex. Even the most experienced practitioners of GRASP need time (days) to re-familiarise themselves with the procedures and understanding of the model, especially if the model is not being used regularly.

The training of 40 pasture scientists in this project has created a potential explosion of need for advice, support and re-skilling. Thus, the project has to some extent, built a dependence on regular practitioners to service these needs.

To address this problem, the project team are forming a user group to provide a continuity of use in applications for industry. The user group would provide the necessary human environment to support and refresh ‘irregular’ users, train new users in workshops, and provide a basis to service enquiries, and develop self reliance. Financial support would be required to facilitate the continuity of such a group (in a formal project or sub-project).

5. Future GRASP model development and applications

The success of GRASP over the last 30 years is that it has always been relevant and operational in delivery to industry and government. However, by definition, the model is not reality, and hence the model has always had well defined boundaries in its application (Section 4.2). As new issues emerge for the grazing industry, there is a need to further develop GRASP (and other models).

Woody plant dynamics

For example, the understanding of woody species dynamics has implications for: livestock carrying capacity, carbon/nutrient cycles, landscape design, greenhouse gas emissions, carbon offsets, biodiversity, resource sustainability and downstream effects of grazing/woodland management. The treatment of trees in GRASP is simplistic - concentrating on competitive and beneficial effects of only static tree densities.

Other models have been developed to address components of the tree dynamics (FLAMES, Liedloff & Cook 2001; CENTURY, Parton *et al.* 1989, 1993; GOLDENWING, J. Carter personal communication). The latter model has been developed in a version of GRASP and hence could be further developed to address some of the issues associated with woody species dynamics. A brief description of the GOLDENWING model is given in Chilcott *et al.* (2008).

Climate change impacts

Similarly, climate change is an emerging issue affecting livestock carrying capacity, pasture quality and animal nutrition, animal health and production, hydrology, nutrient cycles and woodland dynamics. GRASP has slowly been developed to address some of these issues (Hall *et al.* 1998, Howden *et al.* 1999a,b, Howden *et al.* 2001a,b, Moore *et al.* 2000, Cobon 1999, Cobon and Clewett 1999, Crimp *et al.* 2002, Cobon and McKeon 2003, Cobon *et al.* 2005, Cobon *et al.* 2007, Cobon *et al*. 2007).

The advantage that GRASP has in regard to addressing climate change impacts, is its application across a wide range of climates in northern Australia and rangeland regions of Australia. Thus, GRASP is well placed to evaluate likely climate change impacts. Developmental work on assessing climate change impacts with GRASP will continue as part of G. McKeon's Land and Water Australia Fellowship as well as with other colleagues and agencies.

In early 2008, as part of work conducted for the Garnaut Climate Change Review, GRASP has been used to assess the impact of climate change on livestock carrying capacity across Australia. This study built on earlier work by Hall *et al.* (1998), McKeon *et al.* (2000), Carter *et al.* (2000), and Crimp *et al.* (2002). These current and past studies support the view that GRASP has an important role in evaluating the potential impact of climate change on northern Australia's grazing industries.

7.2 Conclusion

The project was very successful in terms of the overall aim of establishing a consistent modelling platform for the use of GRASP and in delivering pasture growth outputs to the grazing industry through the Grazing Land Management education package. The project was also successful in training new users and introducing GRASP and its underpinning biophysical concepts to a greater number of pasture scientists across northern Australia and Australia's rangelands.

The future challenge is to better address the continuing and emerging issues of climate change, resource sustainability and financial viability for the grazing industries and the resource that supports them. For GRASP to continue to address this challenge, it will be necessary to maintain the existing modelling knowledge and computer expertise to support, train and refresh pasture scientists.

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8.1 Glossary

Activist: Person who generally want to run model prior to knowing internal details of model
APSIM/Subroutine GRASP: which combines Subroutine GRASP with the APSIM model (McCown *et al*. 1996)
AussieGRASS: the spatial version of the point GRASP model. It has been parameterised for 185 pasture communities across Australia's grazing lands (Carter *et al.* 2000)
CedarGRASP: the version of the GRASP model coded in FORTRAN90 by N. Flood. The computer code aims to adhere to the high standard of coding design and is designed to allow future programmers to make changes and add new sub-models
CINRS: Climate Impacts and Natural Resource Systems group
Code: computer language written to perform executions/calculations is termed as code
Command prompt: DOS prompt
Comment: statement that can be made in code or at the end of a management record that gives insight to an observation or piece of programming
Control file: used in cedar version of GRASP onwards (.ctl). Controls where the input files will be read from and outputted. Also the details of output that is to be generated (e.g. type, average, column size)
CoPlot: computer graphing package
DAQ124: Historic suite of reports including: subroutine GRASP; SWIFTSYNpD pre-schedule
DOS: Disk operating system
ENTERPRISE: the herd dynamics financial model of a beef cattle property developed by N. MacLeod and A. Ash. It uses GRASP output as input
Exclosure: area of land selected to be fenced to exclude all animals from entering for the purpose of examining soil and pasture attributes. See SWIFTSYNpD pre-schedule
Factorial: Same for matrix
Fatal error: error message programmed into code that warns the model user that will not allow the simulation to proceed any further. For example: Error in data (e.g. soil water value too low) will have to be rectified before simulation will run
File extension: ending of file that describes what data that file contains and is used for. For example: an .mrx contains management records; a .p51 file contains climate records)
Fortran 77/90: (Formula translation) computer programming language: Fortran '77' written in 1977; Fortran '90' written in 1990.
Genetic Algorithm: A computing process that allows 'optimisation' to occur.
GIX: Pasture Growth Index (0-1)
GLM: Grazing Land Management education package developed by MLA and uses tables of pasture growth simulated by GRASP
GMF: GRASP met file – different to .p51 allowing greater flexibility
GRASP Calibrator: GRASP Calibrator is a front-end to the Cedar GRASP model with the main aim of making it easier to calibrate the model to observed data. Written in Microsoft Visual Studio 2003, it is a Win32 executable. It provides a graphing system which displays both time series and observed and predicted data. It includes some simpler observed versus predicted statistical analysis calculations. The Growth Analysis section allows key relationships in the model to be examined.
GRASP: GRASs Production (short for grass production) - the name given to the soil water pasture growth model. Various versions of computing code are available

Grass basal area/cover: percentage of ground covered by live base of tussock (usually 2-10%)
GUNSYNpD Grass Under Nutritional Stability: Yield Nitrogen and phenology Development): The GUNSYNpD project sought to collect detailed field information on native pasture growth from a wide variety of pasture communities across Queensland. The information collected provided parameters for the GRASP model, enabled testing of the model's generality and served as a basis to test modifications to the model. Data were collected every 3 weeks during the growing season and 6 weeks in winter/dry season. SWIFTSYNpD is a simpler version of the data collection (4 samplings per year).
Input file: text file that is read in by model for calculation
Live weight gain: amount of weight gained by grazing animals
LWW: the Land Water and Wool program funded jointly by Land and Water Australia and Australian Wool Innovation Limited
Management records merger: tool that formats management records into a .mrx file with correct character widths for model input
Matrix: Combinations of parameters e.g. soils x species.
MiniSYNpD: Minimal data set collected to measure seasonal pasture growth, as opposed to full SWIFTSYNpD and a complete GUNSYNpD.
MLA: Meat and Livestock Australia – formerly MRC (who funded the project 'Improving Grazing management using the GRASP model' NBP.338)
MRC: Meat Research Corporation – now MLA
Nitrogen uptake: uptake of available nitrogen from the soil by grass
Online SWIFTsheet: Excel spreadsheets that have been formatted (with formulae) to take data from field sampling. An 'exporter' tool can be used to convert the relevant values to produce an .mrx file
Optimisation: A process for finding the best fit of a parameter set to observed data.
Output file: text file that is generated as a result of simulation run
P51 merge: tool that allows daily rainfall file (.dr2) to be merged with .p51 file
Pan evaporation: measured amount of evaporation from a water filled Class A pan (with birdcage)
Parameter file: text file that contains many parameters that influence calculations performed in model (e.g. default.prv)
Parameter set: file that contains many parameters which is read in for model calculation
Parameter: quantities or values that define certain relatively constant characteristics of systems or functions. When determining the response of the system over a period of time, the independent variables (e.g. transpiration) are modulated, while the parameters (transpiration efficiency) are held constant. Whether a quantity is a parameter or a variable is generally determined by its role in a particular system or function, rather than by anything intrinsic to the quantity
Pasture growth: Growth of pasture calculated from model, an input into 'total standing dry matter' (tsdm)
Pasture sward: GRASP is a single sward model with parameters optimised for specific pasture communities being the average across a range of species in the sward
PERFECT model: A soil water balance and crop growth model from the QDPI cropping systems model PERFECT (Littleboy *et al*. 1992) including runoff and soil loss
Plant available water capacity: amount of water a soil can hold that is available for plant use
Pragmatist: Person who generally wants to know what use model is before running it
QCCCE: Queensland Climate Change Centre of Excellence
QDNR: Queensland Department of Natural Resources and Mines
QDNW: Queensland Department of Natural Resources and Water

QDPI&F: Queensland Department of Primary Industries and Fisheries
QNR&W: Queensland Department of Natural Resources and Water
Reflector: Person who generally wants to know the accuracy of the model before using output
SILO http://www.bom.gov.au/silo/ **:** source of meteorological and agricultural data.
Simulation: a model run with a set of parmeters
Spaghetti GRASP: Greg McKeon's developmental version (PC-DOS version)
Spatial GRASP: simulates for the Queensland Drought Alert Project. The UNIX version is maintained by John Carter
Spreadsheet: computer program (e.g. Excel) that allows data to be ordered and formatted for input and output from model. Also contains a graphing package
Stack: model simulation of different treatments/experiments run together
Stacks: An input .mrx file that contains a number of separate simulation experiments for example each paddock in a grazing trial
Standing dry matter (TSDM): Total pasture measured at a particular point in time.
Stocktake: Spreadsheet (Excel) livestock feed budgeting tool used in Grazing Land management package
Submodel: A model component of GRASP devoated to one or two biophysical processes.
Subroutine GRASP: A single piece of FORTRAN code, referred to as "Subroutine GRASP" was developed as a result of an historic workshop
Subroutine: a portion of code within a larger program, which performs a specific task and is relatively independent of the remaining code
SWIFTSYNpD site: area of land selected to erect an exclosure to obtain field data (pasture, soil) to run GRASP model. see SWIFTSYNpD preschedule
SWIFTSYNpD: SWIFTSYNpD methodology is an abbreviation of methods used in the GUNSYNpD project. The objective of the SWIFTSYND methodology is to specify a minimum data set from which relationships can be drawn to simulate pasture growth at a site. Requirements are written in the SWIFTSYNpD methodology/preschedule
TBA: Tree Basal Area (m^2/ha)
Text editor: computer program (e.g. Ultra edit, wordpad, notepad) that allows data to be read in basic (text format). Different programs offer different features.
Theorist: Person who generally wants to investigate the biology and physics of the model
Transpiration efficiency: amount of biomass produced per mm of transpiration
Transpiration: amount of soil water that is used by the plant
Tree basal area: area of ground used by tree trunks or cross sectional area of trunks
Ultra edit: a text editor – to view data in simple (ASCII) format
UNIX: officially trademarked as **UNIX®** is a computer operating system originally developed in the 1960s and 1970s. Unix operating systems are widely used in both servers and workstations
User defined parameter/threshold: the use indicates a value at which something happens or doesn't happen
Utilisation: ratio of eaten/pasture growth
Variable: represents an *unknown* quantity that has the potential to change; in computer science, it represents a place where a quantity can be stored. Variables are often contrasted with constants, which are known and unchanging
Water balance module: water cycle in model described by: rainfall partitioned into infiltration and runoff using functions that relate runoff to surface cover and rainfall intensity. Other components are evaporation, evapo-transpiration and drainage

Water-use-efficiency of the pasture: the amount of above ground dry matter production per mm of transpiration. It is assumed that water-use-efficiency is related to soil fertility and species composition
WATSUP simulation model: GRASP is based on the WATSUP simulation model by Rickert and McKeon (1982) and was improved into what has since been known as the GRASP model (McKeon *et al.* 1982)
Wilting point: soil water content at which plants can not extract water from the soil
WinGRASP: Windows 95 version of GRASP
.dr2: daily rainfall file that can be merged with .p51 file
.exe file: executable file; runs a program
.ini: initialisation file
.mra file: management record file that takes mainly animal (liveweight) observations – used for archival purposes
.mrx file: management record file that store any observation – pasture, liveweight, resets, etc. at a site or paddock
.P51 file: an ascii (text) file which contains a number of different climate variables in a daily format including: maximum and minimum temperature (^{0}C), rainfall (mm), class A pan evaporation (mm), total daily solar radiation (MJ/m^2), and 9am vapour pressure (mb)
.prn file: print text file
.**prv file:** default parameter file
.v51: daily climate file – no longer used

9 Appendices

9.1 CedarGRASP

Appendix 9.1 (N. Flood) presents a summary of documentation that describes the use of the Cedar GRASP version. The availability and location of more detailed documentation is given in Appendix 9.13.

9.2 Evaluation of the GRASP workshop – Northern Australia

Appendix 9.2 provides an overall evaluation carried out by D. Cobon of the GRASP Workshop for pasture scientists working in Northern Territory and north-western Australia.

9.3 Evaluation of the Grasp workshop – Arid Zone of Australia

Appendix 9.3 provides an overall evaluation carried out by D. Cobon of the GRASP Workshop for pasture scientists working in the arid zone of Australia.

9.4 Evaluation of the GRASP workshop – Sub-humid Queensland

Appendix 9.4 provides an overall evaluation carried out by D. Cobon of the GRASP Workshop for pasture scientists working in the sub-humid Australia.

9.5 Participants at GRASP training workshops

Appendix 9.5 lists the participants at the three major training workshops, as well as other workshops conducted during the duration of the project.

9.6 List of demonstrations (1-4)

Appendix 9.6 provides examples of four demonstrations (G. Stone, G. McKeon and P. Timmers) developed as part of the training workshops. The demonstrations provide a step-wise procedure to allow users to carry out simple simulation and calibration tasks.

9.7 New runoff equations in GRASP

Appendix 9.7 (G. Fraser) describes the development of new runoff models and associated variables such as rainfall intensity, for use in CedarGRASP. Much of this work was carried out by G. Fraser as part of his MLA funded PhD Thesis.

9.8 Technical report on modelling minimum nitrogen concentration

Appendix 9.8 (G. McKeon) reviews the effect of nitrogen on native pasture growth, particularly concentrating on factors which affect minimum nitrogen concentration. This area of research was identified as a major limitation in the use of GRASP in environments where pasture fertility, rather than water availability, was the major limitation to pasture growth.

9.9 Pasture utilisation and animal intake: A draft review

Appendix 9.9 (G. McKeon and G. Stone) reviews the many ways in which the term 'pasture utilisation' has been used across a range of field studies and extension applications. The review also documents the large number of estimates of animal intake that are available for use in calculating pasture utilisation. The review is still in a draft stage as the project team are completing a comprehensive review of scientific literature and practical applications.

9.10 Detailed procedure for calculating pasture utilisation

Appendix 9.10 details the procedure developed by G. Stone to calculate pasture utilisation using a new model of animal intake (McLennan and Poppi 2004). The analysis of grazing trials using a standard process to calculate pasture utilisation would allow the interpretation of responses to be brought together in a uniform way.

9.11 A review of procedures for developing land-type parameter sets

Appendix 9.11 reports the initial review carried out in the project to develop land-type parameter sets. The review documents the various approaches available and the reasons for the approach adopted to deliver it within the timeframe of the project.

9.12 Land-type parameter sets

Appendix 9.12 lists the details of over 250 land-type parameter sets developed by C. Chilcott and colleagues that were used in pasture growth simulations presented in the Grazing Land Management Education package workshops.

9.13 List of documentation including manual

Appendix 9.13 lists the various documentation sources and their location that are used to support the Cedar GRASP version of the model.

9.14 GRASP Calibration steps for GUNSYNpD/SWIFTSYNpD data

Appendix 9.14 describes the collection of data using the SWIFTSYNpD methodology and the calibration steps developed by R. Cowley and J. Scanlan. Some examples of previous calibrations studies conducted by M. Cobiac and J. Carter are also presented.

9.15 Native pasture growth studies at Brian Pastures

Appendix 9.15 (K. Day) summarises the collection of native pasture growth data at seven sites at Brian Pastures Research Station, Gayndah, south-east Queensland since 1994. Several of these sites were set up in the initial GUNSYNpD year (1986/87) and hence, represent the longest time series of pasture growth data in Queensland, if not Australia. These studies provide an independent test for previously developed pasture growth parameters, as well as the ranking of land-types in terms of pasture productivity.

9.16 ENTERPRISE model

Appendix 9.16 (A. Ash and C. McDonald) describes in detail the CSIRO SE ENTERPRISE model developed to simulate the herd dynamics and financial performance of a beef cattle enterprise. The ENTERPRISE model uses output from the GRASP model to simulate year-to-year variability in pasture utilisation and liveweight gain. Thus, the ENTERPRISE model provides a procedure for evaluating simulation from GRASP in terms of financial indicators.